

NATIONAL DAMAGES OF
AIR AND WATER POLLUTION

By

H. T. Heintz, Jr.
A. Hershaft
G. C. Horak

Contract No. 68-01-2181

Project Officer
Thomas E. Waddell
Office of Research and Development

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF HEALTH AND ECOLOGICAL EFFECTS
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20460

DISCLAIMER

This report has been reviewed by the Office of Research and Development, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

PREFACE

This final report on the "National Damages of Air and Water Pollution" is submitted under U.S. Environmental Protection Agency Contract #68-01-2821. The material in this report is organized under three chapters presenting the conceptual foundation of estimating pollution damages, air pollution damages estimates, and water pollution damage estimates, respectively. The first chapter contains an appendix describing a related study of human population at risk to various levels of air pollutants. Appendices to subsequent chapters explain in detail the assumptions and calculations employed in obtaining the damage estimates.

The work presented here was performed by Dr. H. Theodore Heintz, Jr., Senior Economic Consultant, Dr. Alex Hershaft, Director of Environmental Studies, and Mr. Gerald C. Horak, Staff Economist, with the assistance of Messrs. Erik Jansson and G. Bradford Shea, all of Environmental Control. Ms. Anita Calcote was responsible for final typing and production of the report.

Review and many valuable comments on the earlier draft were provided by Dr. A. Myrick Freeman, III - Bowdoin College, Dr. Thomas D. Crocker - University of Wyoming, and Dr. Joe B. Stevens - Oregon State University. The helpful guidance and forbearance of Drs. Fred H. Abel, Dennis P. Tihansky, and Thomas E. Waddell of the U.S. EPA's Washington Environmental Research Center are gratefully acknowledged.

ABSTRACT

This report presents updated estimates of the national damages in 1973 of air and water pollution. Information on pollution damages heretofore scattered among numerous sources has been compiled and updated to reflect "best estimates" of the economic significance of the impacts of air and water pollution. The conceptual foundations of damage estimates are discussed.

The source studies for each damage category are surveyed, and updated best estimates including a range to represent their uncertainty, are then developed. Best estimates of air pollution damage are developed for the following categories: human health, \$5.7 billion; aesthetics, \$9.7 billion; vegetation, \$2.9 billion; and materials, \$1.9 billion. The total best estimate for air pollution damages is \$20.2 billion with a range of \$9.5 to \$35.4 billion. A methodology for estimating human populations at risk to air pollutant levels is described.

Best estimates of water pollution damages are developed for the following categories: outdoor recreation, \$6.5 billion; aesthetics and ecological impacts, \$1.5 billion; health damages \$0.6 billion; and production losses, \$1.7 billion. The total best estimate for water pollution damages is \$10.1 billion with a range of \$4.5 and \$18.7 billion.

The caveats qualifying these damage estimates are discussed. Even so, the study recognizes that tradeoffs are inherent in any decision making process and a better understanding of those tradeoffs will allow for improved decision making.

TABLE OF CONTENTS

	<u>Page</u>
PREFACE	iii
ABSTRACT	iv
LIST OF FIGURES	viii
LIST OF TABLES	viii
I. INTRODUCTION	I-1
A. Purpose and Scope	I-1
1. Background	I-1
2. Purpose and scope	I-3
B. Conceptual Foundations	I-5
1. Benefit estimates	I-5
2. Damage functions	I-7
3. Valuation of effects	I-11
4. Aggregation of results	I-13
5. Representation of uncertainties	I-15
APPENDIX. HUMAN POPULATION AT RISK TO VARIOUS LEVELS OF AIR POLLUTANTS	I-19
1. Introduction	I-19
2. Study design	I-20
3. Study performance	I-23
4. Conclusions	I-26
II. DAMAGES OF AIR POLLUTION	II-1
A. Overview	II-1
1. Summary of results	II-1
2. Procedures	II-2
B. Damages to Health	II-5
1. Survey of source studies	II-5
2. Damage estimates	II-9
C. Aesthetic Damages	II-12
1. Survey of source studies	II-12
2. Damage estimates	II-14
D. Damages to Vegetation	II-16
1. Survey of source studies	II-16
2. Damage estimates	II-21

TABLE OF CONTENTS
(continued)

	<u>Page</u>
E. Damages to Materials	II-23
1. Survey of source studies	II-23
2. Damage estimates	II-25
F. More Elusive Damages	II-27
APPENDIX. CALCULATION OF AIR POLLUTION DAMAGES	II-32
1. Calculation of air pollution damages to health	II-32
2. Calculation of aesthetic damages of air pollution	II-37
3. Calculation of air pollutant damages to vegetation	II-37
4. Calculation of air pollutant damages to materials	II-38
III. DAMAGES OF WATER POLLUTION	III-1
A. Overview	III-1
1. Summary of results	III-1
2. Procedures	III-2
B. Damages to Outdoor Recreation	III-4
1. Survey of source studies	III-4
2. Damage estimates	III-7
C. Aesthetic and Ecological Damages	III-10
1. Survey of source studies	III-10
2. Damage estimates	III-11
D. Damages to Health	III-12
1. Survey of source studies	III-12
2. Damage estimates	III-12
E. Production Damages	III-14
1. Nature of production damages	III-14
2. Survey of source studies	III-16
3. Damage estimates	III-18
F. Property Value Damages	III-22
1. Survey of source studies	III-22
2. Damage estimates	III-23

TABLE OF CONTENTS
(continued)

	<u>Page</u>
APPENDIX. CALCULATION OF WATER POLLUTION DAMAGES	III-28
1. Calculations for outdoor recreation damages from water pollution	III-28
2. Computations for aesthetic damage of water pollution	III-37
3. Computations for production damages of water pollution	III-38
4. Computations for health damages from water pollution	III-45

LIST OF FIGURES

<u>No.</u>		<u>Page</u>
I-1	Hypothetical Damage Function	I-9
I-2	Particulate Isopleths for Denver (1973)	I-25

LIST OF TABLES

I-1	Population Characterized by Socioeconomic and Demographic Factors Exposed to Classes of Air Pollutant Concentrations	I-27
I-2	Population Characterized by Socioeconomic and Demographic Factors Exposed to Classes of Air Pollutant Concentrations	I-28
I-3	Population Characterized by Socioeconomic and Demographic Factors Exposed to Classes of Air Pollutant Concentrations	I-29
I-4	Population Characterized by Socioeconomic and Demographic Factors Exposed to Classes of Air Pollutant Concentrations	I-30
I-5	Population Characterized by Socioeconomic and Demographic Factors Exposed to Classes of Air Pollutant Concentrations	I-31
II-1	Estimated National Damages of Air Pollution for 1973	II-1
II-2	Availability and Reliability of Information on Air Pollution Damages	II-2
II-3	Listing of Property Value Studies	II-13
II-4	Estimated Air Pollution Damage to Vegetation	II-21
II-5	Materials Damage Estimates	II-26
II-6	Studies Comparing Vegetation Yields with Seasonal Ozone Levels	II-39
III-1	Estimated National Damages of Water Pollution for 1973	III-1
III-2	Availability and Reliability of Information on Water Pollution Damages	III-2
III-3	Potential Annual Economic Damages to Recreational Users from Water Pollution	III-8

LIST OF TABLES
(continued)

<u>No.</u>		<u>Page</u>
III-4	Estimated National Production Damages Attributed to Water Pollution, 1973	III-18
III-5	Potential Annual Economic Damages to Recreational Users from Water Pollution	III-29
III-6	Estimates of Annual Health Damages from Drinking Water Quality	III-46

I. INTRODUCTION

This chapter sets the scene for presentation of the actual estimates of national damages of air and water pollution in subsequent chapters. The topics covered are the purpose and scope of this project and the conceptual foundations of pollution control benefit analyses.

A. PURPOSE AND SCOPE

This section presents the purpose and scope of this effort in terms of its background, purpose, objectives, scope, and plan of work, as well as the organization of the report.

1. Background

Nearly everyone is now satisfied that there exists a causal relationship between environmental pollution levels and certain damages suffered by society. These may take the form of increased incidence and prevalence of disease, diminished recreational experience, decreased property values, reduced crop yields, more frequent maintenance and replacement of exposed materials, and other, less well-identified losses. This being the case, a reduction in pollutant levels through implementation of pollution controls should bring about a corresponding decrease in these damages and produce a set of benefits equivalent to the difference in damages with and without the controls.

Legislators, planning officials, and other environmental decision makers are frequently faced with the decision of how much pollution control to apply, in the light of the associated direct costs of pollution control and possible secondary economic impacts. In the past, the rationale for these decisions was rather obvious and they were frequently made in response to popular sentiment. However, with the passing of time, the costs became more acutely felt, especially in the wake of the energy crisis. At the same time, the beneficial effects of reduced, or stable, pollution levels were neither obvious, nor easily measured. Clearly, the

decision makers needed a more sensitive tool for comparing and trading off the costs and benefits of various levels and types of pollution control.

It was this need that spawned renewed interest in environmental benefit/cost analysis, or benefit assessment research. Admittedly, this is not an exact science, primarily because social benefits and costs are diffuse and frequently difficult to express in monetary terms. Even so, the process of logical and systematic scrutiny inherent in benefit/cost analysis provides a better insight into the environmental problems, the underlying causes, the associated effects, and potential solutions. Consequently, the process itself can contribute substantially to the ability of decision makers to improve the social welfare through more efficient allocation of the limited resources of the public treasury.

This potential contribution of benefit/cost analysis was recognized by the framers of the National Environmental Policy Act of 1969 (PL 91-190), primarily in Sections 102 and 204. Section 102 calls for the "identification and development of methods and procedures which will ensure that presently unquantified environmental amenities and values may be given appropriate consideration in decision making, along with economic and technical considerations." Section 204 charges the Council on Environmental Quality to gather, analyze, and interpret timely and authoritative information concerning the conditions and trends in the quality of the environment.

In recent years, there have been a number of estimates of benefits of air and water pollution control. Among the most notable were the reports on air and water pollution by Waddell (1974) and Unger et al. (1974), respectively. Most of these efforts involved minor improvements in the extrapolation and aggregation of local estimates to the national level as well as inflationary adjustments. There has been little progress in the basic estimates that form the building blocks of the national estimate.

In 1974, the U.S. Environmental Protection Agency's Washington Environmental Research Center was assigned the task of producing a massive report for the U.S. Congress on the costs and benefits of air and water pollution control (U.S. EPA, 1976). The present document is a revised version of Enviro Control's original input to that report. A critical review of the benefits research program is being published by Enviro Control under separate cover (Hershaft et al., 1976).

2. Purpose and Scope

The purpose of this project is to assist public decision makers by providing some quantitative measure of the national benefits of controlling air and water pollution. This should prove especially valuable in understanding the nature and sources of pollution control benefits, in allocating limited pollution control resources, and in determining the desirable degree of control.

The scope of this effort can be characterized in terms of pollutants, their effects, affected populations, geographic areas, and time frame. In the case of the first item, all pollutants known or suspected of having a significant effect are considered. The damage categories adopted here for air and water pollution are as follows:

<u>Air Pollution</u>	<u>Water Pollution</u>
<ul style="list-style-type: none"> ● Human health ● Aesthetic and recreation ● Vegetation ● Materials 	<ul style="list-style-type: none"> ● Outdoor recreation ● Aesthetic and ecological ● Human health ● Production (municipal, industrial, and agricultural supplies; commercial fisheries; materials damage)

The gross national damage estimates in each category are obtained by extrapolating and aggregating results of scattered local studies. The extent of disaggregation of individual pollutants and damage categories provided in the source studies is generally preserved here. The additional breakdown of damages by population classes is possible, but the substantial effort involved is beyond the means of this study. Finally, the time frame for the entire effort is the year 1973.

The specific estimates in this report were derived in most cases by revising previous estimates to reflect improved extrapolation and aggregation techniques and changes in the economic and demographic conditions. The principal source for air pollution control benefit estimates was Economic Damages of Air Pollution (Waddell, 1973), whereas benefit estimates for water pollution control were derived in conjunction with the preparation of a paper by Abel, Tihansky, and Walsh (1975). The sources of data and techniques employed in arriving at specific estimates are described in detail in the appendices.

The material in this report is organized under three chapters, presenting the conceptual foundations of estimating pollution damages, air pollution damage estimates, and water pollution damage estimates, respectively. The first chapter contains an appendix describing a related study of human population at risk to various levels of air pollutants. Appendices to subsequent chapters explain in detail the assumptions and calculations employed in obtaining the damage estimates.

B. CONCEPTUAL FOUNDATIONS

This section takes up the conceptual foundations of estimating pollution control damages and benefits. The topics covered include nature and role of benefit estimates, damage functions, valuation of effects, aggregation of results, and representation of uncertainties. Most of this discussion is abstracted from the two publications by Hershaft et al. listed in the bibliography.

1. Benefit Estimates

Benefits of controlling air and water pollution arise from the reduction of damages caused by pollution, or the increase in available options. Costs of pollution control are defined here as the resources expended on pollution control programs leading to the reduction in damages. The Council on Environmental Quality refers to damages of pollution as damage and avoidance costs and to costs of pollution control as abatement and transaction costs.

Individuals can experience damages in a number of ways which can be classified as:

- Unavoided damages
- Avoidance damages
- Non-user damages.

Unavoided damages are all those losses of goods and services which an individual is unable or unwilling to avoid. These include damages to health, vegetation, and materials, as well as aesthetic damages. Avoidance damages, on the other hand, are those losses incurred in the process of preventing pollution damages. Examples are treatment of water supplies, planting of less susceptible crops, painting of exposed surfaces, and driving farther to find a less polluted recreation site.

Pollution damages can also accrue to non-users, i.e., people who have no plans of making direct use of an environmental amenity but are nevertheless willing to pay for their restoration and maintenance because of a variety of values. These have been referred to as option, vicarious, preservation, and risk aversion values. In the case of option value, these people are willing to pay for an option of being able to use the clean environment in the future. Vicarious, or bequest, benefits are experienced by people who wish to provide these environmental amenities to others and to future generations. Preservation value is associated with the desire to preserve a unique natural resource. Finally, risk aversion refers to the willingness of people to pay for decreasing or averting the risk of a catastrophic or irreversible damage, such as flooding of arable land or extinction of a biological species.

Estimation of pollution control benefits should ideally follow the steps listed below:

- Project pollutant emissions on the basis of population levels and economic activity for the area and period under consideration
- Estimate reduction of pollutant emissions attributable to implementation of given control policy
- Estimate improvements in environmental quality associated with stipulated reduction of emissions
- Estimate increased uses of the environment associated with improvement in environmental quality
- Estimate regional monetary benefits on the basis of willingness to pay for reduction in adverse effects and other considerations
- Extrapolate and aggregate regional benefit estimates across all regions and time periods of interest to obtain national estimates.

The first two steps involve the projection of a suitable economic scenario and evaluation of the cost effectiveness of various administrative and technological pollution control fixes. The third

step requires the use of complex models of the diffusion and assimilation of specific pollutants within their respective media. The remaining steps rely on the development of damage functions (measurement of effects) and economic benefit analysis (valuation of effects). These topics receive closer scrutiny in the pages that follow.

2. Damage Functions

A damage function is the quantitative expression of a relationship between exposure to specific pollutants and the type and extent of the associated effect on a target population. Exposure is typically measured in terms of ambient concentration levels and their duration and it may be expressed as "dosage" or "dose". The former is the integral of the function defining the relationship between time and ambient level to which the subject has been exposed. Dose, on the other hand, represents that portion of the dosage that has been instrumental in producing the observed effect (e.g., the amount of pollutants actually inhaled in the case of health effects of air pollution).

Dose rate, or the rate at which ambient concentration varies with time, has a major influence on the nature and severity of the resultant effect. Long-term exposure to relatively low concentrations of air pollutants may result in manifestations of chronic disease, characterized by extended duration of development, delayed detection, and long prevalence. Short-term exposure to high concentration levels, on the other hand, may produce acute symptoms, characterized by quick response and ready detection, as well as chronic, cumulative, or delayed effects.

The effect can become manifest in a number of ways and can be expressed in either physical and biological, or economic terms. If the effect is physical or biological, the resultant relationship is known as a physical or biological damage function, or a dose-effect function. In an economic damage function, on the other hand, the effect is expressed in monetary terms. Economic

damage functions can be developed by assigning dollar values to the effects of a physical or biological damage function, or by direct correlation of economic damages with ambient pollutant levels.

The population at risk can consist of one or more human beings, animals, plants, or material substances. Its characterization is crucial to the determination of damage functions for several reasons. First, it serves to define the total damages associated with a given level of exposure by multiplying the corresponding unit damage (e.g., increased mortality) for the specified population at risk (e.g., white males over 65) by the total number of units within this population. Secondly, it permits investigators to adjust their results to reflect the influence of various intrinsic (e.g., age, race, sex) and extrinsic (e.g., general health, occupation, income, and education) variables in assessing the specific effects of air pollutants (e.g., increased incidence of lung cancer). Finally, it can provide useful guidance for allocating pollution control resources by identifying areas with particularly susceptible populations exposed to relatively hazardous levels of pollutants. A recent characterization of the U.S. population exposed to different levels of air pollutants is described in the appendix.

A representative, S-shaped economic damage function, showing the marginal benefits corresponding to a given improvement in environmental quality, is presented in Figure I-1. The lower portion of the curve indicates that, up to a certain exposure value, known as "threshold level", no damage has been observed, whereas the upper portion suggests that there is a saturation level (e.g., death of the target population), beyond which increased pollutant levels do not produce additional damages. The frequent assumption about linearity of a damage function is most valid in the middle, quasi-linear portion where missing data points can be readily interpolated.

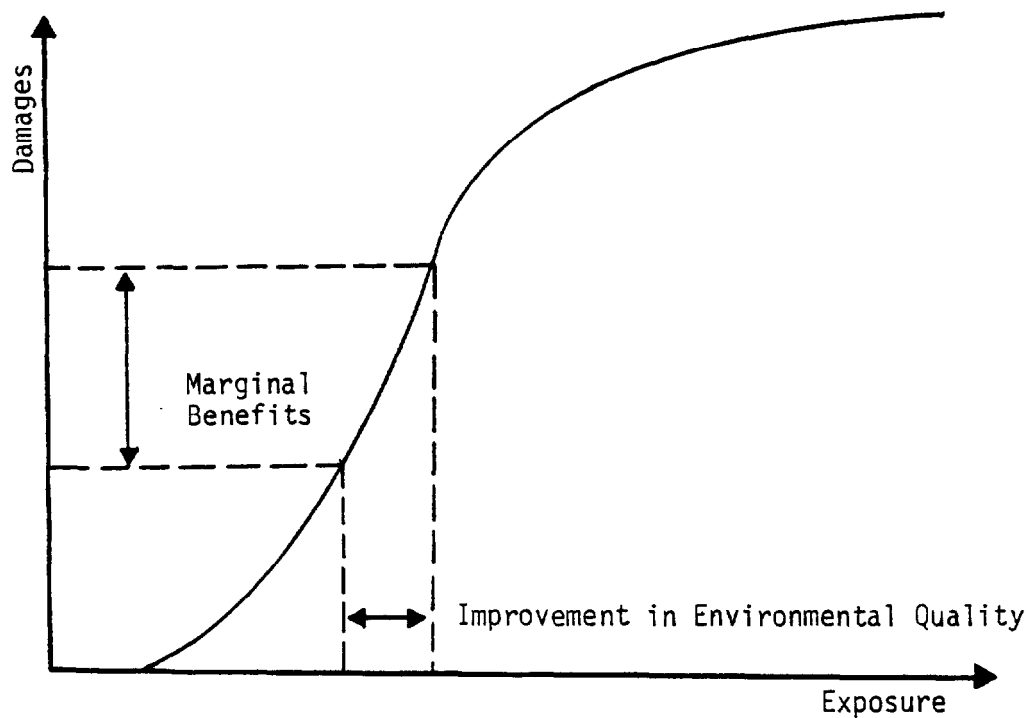


Figure I-1. Hypothetical Damage Function

The data required to develop physical or biological damage functions are obtained primarily through epidemiological, field, clinical, toxicological, or laboratory investigations. The first approach involves the comparative examination of the effects of pollutants on selected segments of population exposed to different levels of pollution, in order to deduce the nature and magnitude of the likely effect. Field observations represent a similar approach to assessment of effects on animals, vegetation, and materials, and they are characterized by similar analytical techniques and concerns. Clinical studies are based on hospital observation of the results of exposure on human subjects. Toxicological investigations involve deliberate administration of controlled doses of pollutants to animal subjects and observation of the resulting effects. Laboratory studies represent essentially the same approach for determining effects of pollutants on plants and materials.

Development of damage functions is beset by a number of major problems that may affect substantially the accuracy and reliability of the resulting benefit estimates. The more important among these are:

- Collection of reliable ambient quality data
- Measurement of exposure
- Selection of representative populations
- Measurement of effects
- Definition of exposure-damage relationship.

Collection of sufficient air and water ambient quality data requires a very large number of measuring stations and a massive commitment of measurement and data handling well in excess of the present level. This is because one is dealing with numerous point and non-point sources of pollutants discharging at irregular intervals into fluid media, where these pollutants are subject to various ill-defined physical forces and chemical interactions. Consequently, the available data seldom reflect hourly, or even diurnal variations that may be important.

The exposure index for each pollutant should be selected to account for both level and duration as well as presence of other pollutants, or influence of meteorological or hydrological factors. The populations studied used to be representative of the population at large in terms of susceptibility to detectable levels of damage. In the case of health effects, this involves segregation based on demographic and socioeconomic makeup of the population at risk.

Measurement of the resultant effects is never easy, but it becomes especially problematic in the case of psychic damages, such as those associated with health, recreation, aesthetics, option, and preservation values. Such damages are not adequately assigned costs by the market system, because they are aspects of environmental use that are neither privately owned nor exchanged through market transactions. Thus, estimation of the corresponding benefits requires development of proxy or surrogate measures.

Finally, damage functions must be frequently plotted through only a few data points. Even small errors in the location of these points or in the assumption about the detailed shape of the curve can lead to major estimation errors.

3. Valuation of Effects

The three common methods for estimating marginal benefits associated with a given reduction in pollution level are known as:

- Alternative cost
- Opportunity cost
- Willingness to pay.

The alternative cost method is based on assignment of monetary values to effects determined with the aid of a physical or biological damage function. This method is employed most frequently, because of its rapid applicability and avoidance of complex economic analysis. However, because there is no provision for substitution or any other mitigative adjustment by the target population, the damage estimate may be excessive. Opportunity cost, on the other hand, is estimated on the basis of the costs of substitution and other adjustment opportunities open to the target population. This method presumes that title to the environmental good is held by the target population, which is then entitled to trade it away for a substitute good.

Finally, the willingness to pay method seeks to determine how much the affected population is willing to pay to avoid a given environmental degradation. Here, the title to environmental quality is presumed to be vested in the perpetrators of environmental degradation, rather than the target population. A variation of this approach, known as the compensation method, assumes that the title is vested in the target population and attempts to determine how much compensation an individual would require to accede to a given loss of environmental quality.

Estimation of benefits on the basis of the individual's willingness to pay entails the intermediate steps of assessing changes in user behavior associated with anticipated reductions in effect and of assessing the marginal willingness to pay associated with these changes. Changes in individual's behavior reflect the ac-

tual changes in environmental quality as well as the individual's perception of these changes. Consequently, they vary with local social customs and economic conditions.

Direct measures of the individual's willingness to pay for changes in environmental quality can be inferred from individual responses to such changes by a number of sophisticated, though imprecise, methods. These are:

- Market studies
- Travel cost studies
- Personal interviews
- Delphi method
- Legislative and litigation surveys.

Market studies, such as those investigating differences in property value or income, employ prices or wages as an indication of the values affected by pollution, and their usefulness has been demonstrated in a number of cases. This approach is heavily dependent on the investigator's ability to identify and isolate the many other factors that affect the value of property, or other indicator used. Travel cost studies seek to determine the additional costs incurred by a user in traveling to a more distant, less polluted recreation site.

Surveys of public opinion based on personal interviews have been particularly helpful in understanding how attitudes about pollution are formed and shaped by changes in environmental quality. The major difficulty with this approach lies in the tendency of respondents to bias their responses in a manner that will advance their particular point of view. Recent innovations in interview and data interpretation techniques have attempted to address this bias. Surveys of legislative decisions or litigation awards can also provide some insights into a collective assessment of the willingness to pay.

Inasmuch as benefits are defined as reduction of damages associated with an improvement in the level of environmental quality, it becomes very important to specify the environmental quality levels being compared. The two levels should be compared within the same time frame, on a "with" vs. "without" pollution controls basis, rather than in a "before" vs. "after" setting, to avoid complications due to inflation, change in relative value of environmental amenities, and other temporal variations. The uncontrolled, "without" level is typically the current or some other value projected on the basis of expected population growth and economic development. The controlled, or "with", levels can be selected from among the following alternatives:

- Zero ambient concentration (highly unrealistic: would involve cleanup of natural sources)
- Zero man-made emissions (again, very unrealistic: would involve extreme control measures)
- Ambient levels corresponding to the respective air quality standards
- Threshold levels (very controversial)
- Projected levels (on the basis of postulated reduction in emissions).

4. Aggregation of Results

Most benefit estimation studies address a specific geographic location, group of pollutants, population at risk, and time period. Extension of these results to the national level and some future time frame requires the extrapolation and aggregation of the regional estimates and projection of a number of variables, including ambient levels, populations at risk, personal incomes, and costs of damages.

Aggregation of benefit estimates entails a tradeoff of detailed information about form and structure in return for treatability and ease of comprehension. Attempts to apply aggregated national estimates to local pollution control decisions can introduce substantial

errors, because the information lost in the aggregation process frequently cannot be recovered. In fact, it may be possible to develop national estimates directly, rather than by aggregation of local studies.

Definition of the benefit categories for which the data are collected are often dictated by availability of sources and analytical expediency, rather than the needs for a uniform, self-consistent framework. Consequently, different studies evaluate damages that are not necessarily additive, or even comparable, and careful interpretive techniques must be applied to these results to prevent gross overlaps or omissions of individual estimates. Moreover, in aggregating such fractional results, it is not possible to reflect the potential impacts of changes in individual components on one another, nor the impact of the general adjustments of the economy and the resulting reduction in damages.

Overlaps and gaps between categories of benefits may arise when two types of effects (e.g., health effects and property values, in the case of air pollution, and recreation benefits and property values, in the case of water pollution) are estimated by different methods which may count the same benefit component twice or fail to capture certain other components. It is important, therefore, to attempt removal of the excess count and to input a value for the missing component. Another problem is the inconsistency in quality of estimates for different benefits categories. Finally, in aggregating over several variables (e.g., pollutants, populations at risk, effects, geographic areas, time periods), it is important to specify the order in which the variables are being aggregated.

If the benefits of interest accrue over a number of years, then it may be useful to compute the present value of the total stream of benefits with the aid of an appropriate discount rate and time horizon. This approach becomes less effective when the projected effects extend over a very long time period that spans several generations, because of the large reduction factor. For

example, using a discount rate of 5 percent, the current benefit of an effect occurring 200 years hence is reduced by a factor of 6×10^{-4} . In such cases, our moral obligation to the future population needs to be considered alongside sheer economic efficiency.

5. Representation of Uncertainties

Uncertainties about benefit estimates arise from errors in the four steps of the estimation process:

- Aggregation
- Valuation
- Specification
- Measurement.

Errors of aggregation are associated with attempts to extrapolate national values from regional estimates and future values from current or past estimates. They arise from overlaps and gaps between benefit categories as well as from temporal variability of user behavior and market conditions. Errors of valuation are due to the difficulty of assigning monetary values to certain physical, biological, aesthetic, or non-user benefits, as well as to biases inherent in direct valuation.

Errors of specification include any type of error in specifying the functional form of the relationship under study or in accounting for important variables. A particularly common and grave error of specification is committed in attempting to extrapolate a complete functional relationship from a few data points that are barely adequate to characterize a small portion of the curve. Even if one were willing to make an assumption about the overall shape of the function, there is frequently no way of knowing which portion is represented by these data points.

Errors of measurement may be attributed to the following factors involved in the benefit estimation process:

- Disparities in location of monitoring stations and subjects
- Errors of pollutant sampling and analysis
- Uncertainties in determining exposure
- Inadequate characterization of population at risk
- Uncertainties in determining effect
- Impact of covariates.

If the errors of measurement of the independent variables are relatively small, occur at random, and follow a normal, or Gaussian distribution about the mean value of each variable, then the total error of all the independent variables can be computed by standard probabilistic techniques. However, this is seldom the case, because measurement of such independent variables as pollutant level, meteorological conditions, and socioeconomic characteristics is subject to errors that are both large and biased. The advantages of the probabilistic approach include an opportunity to incorporate more information in the reported results and the assignment of a probability to the various outcomes. Envelopes characterizing errors and uncertainties of benefit estimates can be also obtained by more practical means, including:

- Replicating a specific study using new data or methods
- Manipulating values of the more important variables
- Combining results of several studies
- Applying "best" and "worst" case assumptions.

Replication and data manipulation are essentially empirical techniques for determining the errors and corresponding confidence bands. Combining the results of several studies is a rare and uncertain opportunity, in light of the great variety of conditions and populations that characterize the different efforts. Application of "best" and "worst" case assumptions is more an argumenta-

REFERENCES

Abel, F. H., D. Tihansky, and R. G. Walsh, National Benefits of Water Pollution Control, U.S. Environmental Protection Agency, Office of Research and Development, Draft, January 1975.

Hershaft, A., et al., Critical Review of Air Pollution Dose-Effect Functions, Council on Environmental Quality, March 1976.

Hershaft, A., et al., Critical Review of Estimating Benefits of Air and Water Pollution Control, U.S. Environmental Protection Agency, Office of Research and Development, May 1976.

Takacs, I. and G. B. Shea, Human Population at Risk to Various Levels of Air Pollutants, U.S. Environmental Protection Agency, February 1975.

Unger, S. G., et al., National Estimates of Water Quality Benefits, U.S. Environmental Protection Agency, November 1974.

U.S. Environmental Protection Agency, Office of Research and Development, The Cost of Air and Water Pollution Control 1976-1985, Draft Report, February 1976.

Waddell, T. E., The Economic Damages of Air Pollution, U.S. Environmental Protection Agency, EPA-600/5-74-012, May 1974.

APPENDIX. HUMAN POPULATION AT RISK TO VARIOUS LEVELS OF AIR POLLUTANTS

This appendix describes the methodology and presents the major results and conclusions of the "Estimation of the Human Population at Risk to Existing Levels of Selected Air Pollutants," performed by Enviro Control, Inc. for U.S. EPA's Washington Environmental Research Center.

1. Introduction

In the past, it was customary to assess the severity of air pollution in terms of point source emissions, and later, in terms of ambient concentrations. These indicators reflected the progression in the state of the art from visual assessment of smoke plumes to increasing availability of air quality monitoring stations and associated data processing capabilities. However, the real significance of air pollution lies in its physical, economic, and social impact on the target population.

Beyond this, characterization of the population at risk in terms of its potential susceptibility to various levels of air pollution can provide useful indications for allocation of resources and setting of priorities in air pollution abatement. For example, a higher clean-up priority could be assigned to an area containing a large population of older people or those exposed to high occupational pollution than to another area with a smaller population of relatively healthy people, not otherwise exposed to harmful pollutants. This procedure can be refined further through control of specific pollutants.

Since the importance of characterizing the population at risk to various levels of air pollutants became recognized, there have been several scattered attempts to obtain such a characterization through crude regional estimates. However, the first comprehensive, national assessment, entitled "Estimation of Human Population at Risk to Existing Levels of Air Quality," was completed by Enviro Control, Inc., for U.S. EPA's Washington Environmental Research Center in February 1975 (Takacs and Shea).

The specific objective of the population at risk study was to calculate the number of people in selected demographic and socio-economic classes who are exposed to various levels of several air pollutants. This was accomplished in six steps:

- Select air quality indices
- Select population indices
- Select air quality and population coverage units
- Obtain and process air quality data
- Obtain and process census data
- Calculate population at risk.

The first three steps constitute the study design, and the last three its performance.

2. Study Design

The pollutants selected were:

- Total suspended particulates
- Sulfur dioxide
- Nitrogen dioxide
- Carbon monoxide
- Photochemical oxidants.

Hydrocarbons were not considered, because they have not been implicated directly in health effects.

The air quality indices were expressed in terms of the relationship of pollutant ambient levels to their corresponding short and long-term primary standards to convey more meaning to the lay reader. They were divided into four classes corresponding to 0-75 percent, 75-100 percent, 100-125 percent, and above 125 percent of the corresponding primary standard. This scheme was modified slightly for particulates to accommodate additional values. Only one-hour data were available for carbon monoxide under the short-term standard, and no long-term standard has been set. Similarly, there is no short-term standard for nitrogen dioxide or long-term standard for photochemical oxidants. In the case of short-term standards, the 90th and 99th percentiles of the observed values were found to be more useful indicators of exposure than the maximum values.

These percentiles are more stable statistically, and their use helps to minimize random errors, which tend to occur at the extremes of a frequency distribution.

Both long-term and short-term exposures represent two important types of exposure hazards. Long-term exposure to relatively low concentrations of air pollutants may result in manifestations of chronic disease, characterized by extended duration of development, delayed detection, and long prevalence, and exemplified by neoplasms and cardiovascular disorders. Short-term exposure to high concentration levels, on the other hand, may produce acute symptoms, characterized by quick response and ready detection and exemplified by fatigue and dizziness, impairment of visual, respiratory, psychomotor, and other functions, as well as increased attacks of asthma and bronchitis.

Human susceptibility and resultant response to toxicological and physical stress produced by air pollutants is determined to some extent by certain intrinsic traits, such as age, race, sex, and general health, as well as by such extrinsic characteristics, as employment, income, educational level, and general environmental conditions. The age subpopulations that are considered particularly susceptible to observable effects are the very young (under 20) and the old (over 65). Genetic makeup, most readily defined along racial lines, is another predeterminant of susceptibility. Sex, a third determinant, is seldom considered, because it is distributed fairly evenly in most community studies.

The type or place of employment is an important indicator of exposure to industrial air pollution, and the subpopulation engaged in manufacturing should be identified as a minimum. Educational level relates to an awareness of the need for proper nutrition, health care, and protection from air pollutants. Finally, family income again correlates with the nutritional and health care levels, but may also serve as an indicator of the willingness to pay for abatement of air pollution in economic studies. Although these intrinsic and extrinsic traits and characteristics are not considered etiological agents of disease, studies of their correlation with health effects have been helpful in isolating the likely agents, such as specific air pollutants, and in shaping social policy.

The population classes selected for this study are listed below:

- Age
 - under 19 years
 - 20-64 years
 - 65 years and over
- Race
 - white
 - negro
 - other
- Employment
 - manufacturing
 - other
- Family income
 - under \$5,000
 - \$5,000 - \$24,999
 - \$25,000 and over.

The candidate geographic units for estimation of the population at risk were standard metropolitan statistical areas (SMSAs), counties, zip code areas, census tracts, and minor civil divisions. The corresponding air quality units could be counties, air quality control regions (AQCRs), or isopleths (equal pollutant concentration contours) drawn between air quality monitoring stations. SMSAs and census tracts were selected for the population coverage and isopleths for the air quality coverage.

An SMSA is an area designated by the Office of Management and Budget for the purpose of facilitating studies of regional needs. It consists of a city with a population of 50,000 or more, or a city of 25,000 with adjoining counties containing 50,000 people. Census data for SMSAs are broken down further by census tracts, each of which contains approximately 4,000 people. Census tracts represent the most accurate data base for the larger SMSAs, while for the smaller SMSAs and rural areas, a breakdown on the county level is sufficient. Attempts at additional detail would be frustrated by the scatter and unavailability of air quality monitoring stations. Minor civil divisions bear the additional liability of being defined differently in different states.

On the air quality side, the AQCRs were called for in the Clean Air Act of 1970, and 247 such regions have been designated by the Administrator of the EPA. Each state is responsible for attaining and monitoring the required air quality in each region within its jurisdiction, and thus, air quality data are readily available. However, the most accurate and thorough method of indicating air pollutant ambient levels in specific geographic locations is with the aid of isopleths, or contours drawn

through equal concentrations of specific air pollutants. The contours can be readily converted to a grid display with the aid of a computer program. Although population information from the U.S. Bureau of the Census is available for the entire country, air quality data are not. Gaps occur in the form specific pollutants, the short-term or long-term values, or altogether missing stations. The study encompassed all of the 241 SMSAs designated at the time of the 1970 census, which covered 68.6 percent of the population and 11.0 percent of the land area of the U. S. However, the population coverage for specific pollutants ranged from a high of 66 percent of the population for short-term suspended particulates to 14 percent - for long-term nitrogen dioxide.

SMSAs and their associated census tracts were selected over other population coverage units, because they provide the desired degree of detail in population classifications, are characterized by suitable air quality data, and contain the bulk of the U. S. population. Pollutant ambient levels in these areas were determined by plotting isopleths between air quality monitoring stations and by superimposing this display over maps of the census tracts.

The year of coverage for air quality data was 1973, the base year for the report on the "Cost of a Clean Environment," though the population information was based on the 1970 census.

3. Study Performance

Air quality data for 1973 were obtained in the form of computer printouts from EPA's National Aerometric Data Bank in Durham, N. C. Data collected by measurement methods designated "unacceptable" by EPA were excluded, but those obtained by Federal reference method (FRM) and "unapproved" methods were utilized to enlarge the data base, especially in the case of nitrogen dioxide.

Information on location of air quality monitoring stations was included with the air quality data, and a supplementary cross-check was obtained from the annual Directory of Air Monitoring Sites. This information has been found accurate in most of the major urban areas, but other

urban and many rural areas suffer from lacking or incorrect geographical coordinates or site addresses. This was corrected by contacting the reporting agencies.

Isopleths indicating equal air pollutant ambient levels were constructed by linear interpolation between monitoring stations (see Figure I-2). This construction requires certain assumptions, which are summarized below:

- If two stations had the same geographic location, an arithmetic mean of the data was taken
- If two stations had readings in the same pollutant class, it was assumed that the intermediate area was in the same class
- If there were no readings in a lower pollutant class, it was assumed that the remainder of the outlying area is in the lowest observed pollutant class.

Isopleths were constructed for all SMSAs having at least five stations reporting air quality data for at least one pollutant which fell into two or more classes. If there were less than five stations reporting per pollutant in an SMSA, it was deemed inadvisable to attempt construction of an isopleth, because of the amount of unwarranted extrapolation involved. In these cases, a simple arithmetic mean of the air quality data was taken to determine the class of air quality for the entire city with regard to that pollutant. There were also SMSAs with more than five stations reporting that did not require isopleth mapping, because all air quality data for each pollutant fell into only one class.

Population information including census tract maps, was obtained from the Series PHC(1) (Population Housing Census) tract reports and from the Fourth Count Census Tape File.

Each census tract was assigned to the appropriate air quality class by superpositing USGS maps containing station locations and associated isopleths over the census tract maps, with the aid of a Saltzman Optical Projector, and making deliberate assignments. The magnitude of this undertaking can be appreciated by noting that New York City alone has nearly 3,000 tracts.

Finally, the population at risk within each SMSA was computed for each pollutant and population class, and then, these data were aggregated to state, regional, and national levels. The results are displayed in several hundred tables, containing matrices of population vs. air quality classes for different combinations of pollutants and geographic locations. The national aggregations for all five pollutants are presented in Tables I 1-5.

4. Conclusions

The study concluded that the exposure of essentially the entire U. S. population surveyed to short-term particulate, short and long-term sulfur dioxide, and short-term carbon monoxide levels was within the respective permissible primary air quality standards. On the other hand, significant portions of the population were exposed to excessive long-term particulate (31%), long-term nitrogen dioxide (24%), and short-term oxidant (58%) levels.

Among the ten EPA regions, Region IX (which includes California) had the largest percentage of the surveyed population exposed to air pollution levels in excess of the national standards for long-term particulates (67%), short-term carbon monoxide (6%), and long-term nitrogen dioxide (35%). Region II (which includes New York state) had the largest population exposed to oxidants (95%), with Region IX close behind (83%).

For the other pollutant indices, even the two leading regions had relatively low population percentages exposed to levels above the standards. For short-term particulates, Region VIII had approximately 7 percent of the population exposed. For long-term SO_2 , Region V had under 2 percent exposed, and for short-term SO_2 , Region IV had the highest exposure percentage, but even this was less than 1 percent.

Table I-1. POPULATION CHARACTERIZED BY SOCIOECONOMIC AND DEMOGRAPHIC FACTORS EXPOSED TO CLASSES
OF AIR POLLUTANT CONCENTRATIONS
(1000 persons)

Area: United States

Air Pollutant: Total Suspended Particulates

Air Quality Index: Short Term - 90th percentile of 24 hour data
Long Term - Annual geometric mean

Population Characteristics	Air Quality Level Classes - $\mu\text{g}/\text{m}^3$									
	Short Term					Long Term				
	< 200	201-260	261-320	321-450	>451	< 60	61-75	76-90	91-120	>121
A. General										
Age: 0-19	47,859	2,004	471	142	105	19,889	10,631	7,054	4,640	2,758
20-64	68,487	2,717	631	205	139	28,434	16,684	8,350	6,802	4,006
65 and over	11,644	462	116	44	19	4,442	2,874	1,650	1,195	670
Race: White	110,532	4,261	904	325	214	47,564	25,309	13,763	10,385	6,443
Negro	14,836	859	301	58	47	4,537	4,553	3,005	1,992	808
All other	1,672	63	13	8	2	664	327	286	260	184
B. Economic										
Annual family income: (thousands of families)										
\$0-\$4,999	5,271	265	66	22	13	1,768	1,313	812	621	324
\$5,000-\$24,999	25,093	963	224	68	52	10,644	6,027	3,220	2,187	1,644
\$25,000 and over	1,876	50	8	3	1	954	408	196	141	111
C. Labor Force										
Percentage in manufacturing	25.4%	26.6%	28.5%	24.8%	19.1%	26.2%	25.1%	27.2%	26.9%	24.0%
D. Total Population	127,990	5,183	1,218	391	263	52,765	30,189	17,054	12,637	7,435

Table I-2. POPULATION CHARACTERIZED BY SOCIOECONOMIC AND DEMOGRAPHIC FACTORS EXPOSED TO CLASSES
OF AIR POLLUTANT CONCENTRATIONS
(1000 persons)

Area: United States

Air Pollutant: Sulfur Dioxide

Air Quality Index: Short Term - 90th percentile of 24 hour data
Long Term - Annual arithmetic mean

Population Characteristics	Air Quality Level Classes - $\mu\text{g}/\text{m}^3$							
	Short Term				Long Term			
	< 280	281-365	366-420	>420	< 60	61-80	81-100	> 100
A. <u>General</u>								
Age: 0-19	49,283	62	2		37,403	399	167	1
20-64	70,412	93	3		53,534	566	214	1
65 and over	12,174	19	1		8,887	118	29	0
Race: White	13,073	161	3		83,921	928	393	2
Negro	16,032	12	3		13,133	145	15	0
All other	1,755	1	0		1,760	10	2	0
B. <u>Economic</u>								
Annual family income: (thousands of families)								
\$0-\$4,999	5,457	6	1		4,057	43	13	0
\$5,000-\$24,999	25,848	37	1		18,394	205	80	0
\$25,000 and over	1,932	2	0		1,554	14	5	0
C. <u>Labor Force</u>								
Percentage in manufacturing	25.4	43.0	14.5		25.2%	23.7%	26.2%	38.9%
D. <u>Total Population</u>	131,869	174	6		99,824	1,083	410	2

Table I-3. POPULATION CHARACTERIZED BY SOCIOECONOMIC AND DEMOGRAPHIC FACTORS EXPOSED TO CLASSED
OF AIR POLLUTANT CONCENTRATIONS
(1000 persons)

Area: United States

Air Pollutant: Carbon Monoxide

Air Quality Index: Short Term - 99th percentile of one hour data

Population Characteristics	Air Quality Level Classes - $\mu\text{g}/\text{m}^3$			
	< 30	31-40	41-50	> 51
A. <u>General</u>				
Age: 0-19	37,356	246	242	191
20-64	54,394	420	407	292
65 and over	9,217	88	89	60
Race: White	86,944	606	509	452
Negro	12,257	127	183	47
All other	1,766	21	46	44
B. <u>Economic</u>				
Annual family income: (thousands of families)				
\$0-\$4,999	4,536	33	42	32
\$5,000-\$24,999	19,788	149	137	84
\$25,000 and over	1,610	13	6	3
C. <u>Labor Force</u>				
Percentage in manufacturing	24.7	13.9	25.0	31.7
D. <u>Total Population</u>	100,967	754	738	543

Table I-4. POPULATION CHARACTERIZED BY SOCIOECONOMIC AND DEMOGRAPHIC FACTORS EXPOSED TO CLASSES
OF AIR POLLUTANT CONCENTRATIONS
(1000 persons)

Area: United States

Air Pollutant: Nitrogen Dioxide

Air Quality Index: Long Term - Annual Arithmetic Mean

I-30

Population Characteristics	Air Quality Level Classes - $\mu\text{g}/\text{m}^3$			
	< 80	81-100	101-125	> 125
A. <u>General</u>				
Age: 0-19	6,268	1,697	2,223	220
20-64	9,034	2,470	3,374	460
65 and over	1,421	472	554	90
Race : White	15,024	3,649	5,364	535
Negro	1,195	966	577	183
All other	504	24	210	52
B. <u>Economic</u>				
Annual family income: (thousands of families)				
\$0-44,999	659	193	243	35
\$5,000 - \$24,999	3,302	905	1,100	139
\$25,000 and over	226	63	104	21
C. <u>Labor Force</u>				
Percentage in manufacturing	23.1%	30.1%	26.9%	27.0%
D. <u>Total Population</u>	16,723	4,639	6,151	770

Table I-5. POPULATION CHARACTERIZED BY SOCIOECONOMIC AND DEMOGRAPHIC FACTORS EXPOSED TO CLASSES
OF AIR POLLUTANT CONCENTRATIONS
(1000 persons)

Area: United States

Air Pollutant: Oxidants

Air Quality Index: Short Term - 99th percentile of one hour data

Population Characteristics	Air Quality Level Classes - $\mu\text{g}/\text{m}^3$			
	< 120	121-160	161-200	> 200
A. <u>General</u>				
Age: 0-19	11,262	6,011	11,326	10,726
20-64	15,900	7,128	16,945	15,306
65 and over	2,630	1,205	3,061	2,424
Race: White	24,909	11,690	26,378	25,008
Negro	4,149	1,576	4,540	2,889
All other	734	178	413	560
B. <u>Economic</u>				
Annual family income: (thousands of families)				
\$0-\$4,999	1,116	561	1,357	1,073
\$5,000-\$24,999	5,911	2,592	6,074	5,616
\$25,000 and over	458	167	530	421
C. <u>Labor Force</u>				
Percentage in manufacturing	24.0%	21.2%	22.0%	21.3%
D. <u>Total Population</u>	29,792	13,444	31,333	28,455

II. DAMAGES OF AIR POLLUTION

II. DAMAGES OF AIR POLLUTION

This chapter presents estimates of national damages of air pollution for 1973. The damage categories covered are health, aesthetic, vegetation, and materials.

A. OVERVIEW

The national estimates are introduced here with a summary of results and a description of the procedures followed.

1. Summary of Results

Estimates of national damages of air pollution for 1973 are summarized in Table II-1 for the four major classes of benefits, in terms of best estimates and corresponding ranges. Both were derived largely by updating estimates based on a number of studies summarized by Waddell (1974). These damages are equivalent to benefits that would accrue annually from reduction of air pollution to threshold levels.

Table II-1. Estimated National Damages of Air Pollution for 1973
(\$ billion)

Damage Category	Best Estimate	Range	
		Low	High
Health	5.7	2.0	9.4
Aesthetic	9.7	5.7	13.7
Vegetation	2.3	1.0	9.6
Materials	<u>1.9</u>	<u>0.8</u>	<u>2.7</u>
Total	20.2	9.5	35.4

To gain a proper perspective of these estimates, it is important to recognize that they do not reflect all of the potential damages from air pollution. There are a number of categories of poten-

tial damages for which estimates are not available. The most important of these is the threat to preservation of the natural environment, including unique ecosystems and species. But, even within the categories for which estimates are available, the existing monetary measures tend to understate the total damages. For example, the estimated health damages reflect the direct and indirect costs of illness, such as health care costs and lost earnings, but do not reflect the value of lost leisure time or the psychic costs of illness and death. Because such omissions are necessitated by lack of data or appropriate studies, the best estimate of \$20.2 billion understates the total damages of air pollution.

2. Procedures

The damage estimates for air pollution were based on the interpretation of the results of numerous studies of varying scope, methodology, and data quality. The availability and reliability of information from these studies is indicated in Table II-2. It will be noted that effects data are most available for effects of SO_x , oxidants, and particulates and for the damage categories of human health and vegetation.

Table II-2. Availability and Reliability of Information on Air Pollution Damages

Categories	Parti - culates	SO_x	NO_x	Oxi - dants	CO	HC's	Other
Human Heal th	IG	IG	SF	SF	SG	SF	IF
Aesthetics	IF	IG	U	SF	U	U	U
Vegetati on	SF	IF	IF	IG	SG	SF	SF
Materi als	SG	IG	SF	IF	SP	SP	U

Avai l a b i l i t y: I - i n s u f f i c i e n t
S - s c a r c e
U - u n a v a i l a b l e

R e l i a b i l i t y: G - g o o d
F - f a i r
P - p o o r

In general, the procedure followed was to review the assumptions and data used in each of these previous studies which contained estimates of damages or benefits. Damages estimates were recalculated in terms of 1973 dollars by updating the original assumptions and data to reflect changes that had occurred between 1973 and the date of the original assumptions and data. Thus, the estimates shown in Table II-1 and discussed in subsequent sections reflect 1973 price levels, population, mortality and morbidity rates, housing stock and other key variables.

The estimates also reflect the assumptions common to most economic analyses, namely that the capacity of the economy is fully employed and that prices adequately reflect the opportunity costs of resources and the value of final goods and services.

The benefits of specific pollution control decisions and actions are generally measured in terms of the gains produced by expected improvements in ambient quality that would result from these actions. Thus, the analysis of benefits should be based on specification not only of the pollution control policies (such as best practicable technology, best available technology, or zero discharge), but also of the anticipated economic and social conditions which will shape environmental uses and attitudes during that period.

However, in order to circumvent the many difficulties associated with postulating future emission levels under alternative control options and the associated ambient quality levels, the benefit estimates presented in this report correspond to total damages attributed to current pollution levels. Such benefits would be realized only if emissions were reduced to a point corresponding to ambient quality levels below those associated with observable damages. Such levels, commonly referred to as threshold levels, were used in establishing current air and water quality standards.

In combining estimates from different classes of damages, care has been taken to minimize double counting. For example, studies of the differences in residential property values associated with dif-

ferences in air pollution reflect primarily the aesthetic and soiling effects, rather than health effects. This is based on the argument that the aesthetic effects are experienced directly in everyday life, whereas health effects are mostly long-term, and are not distinguishable by the general population from other causes of illness. Although improved education may be altering people's awareness of the health effects of air pollution, it is not likely that this has been reflected in past property values, on which these benefit estimates have been based.

B. DAMAGES TO HEALTH

Damages by air pollution to human health are both the most publicized and most under-valued category of air pollution damages. The estimate reported here represents only the most readily monetized component of the total damage.

1. Survey of Source Studies

The major air pollutants that have been linked to health damages are suspended particulates, sulfur oxides, nitrogen oxides, oxidants, and carbon monoxide. The effects of these pollutants are increased morbidity (incidence and prevalence of disease) and mortality. Common measures of morbidity have been absenteeisms from work and school, hospital admissions and residence days, visits to clinics and doctors' offices, expenditures for certain drugs, automobile accidents, and personal diaries.

The specific diseases that have been associated with air pollution are bronchitis, emphysema, asthma, respiratory infections, heart disease, cancer of the respiratory and digestive tracts, and chronic nephritis. The quantitative relationships between these diseases and air pollutant levels have been explored in a number of studies. However, only a few of these yield quantitative information suitable for estimation of damages.

A number of important cross-sectional studies have compared the effects of sulfur oxides and particulates on populations of metropolitan areas. Lave and Seskin (in press) investigated the relationship between sulfate and particulate pollution and mortality rates in more than 100 SMSAs, using multivariate regression analysis and controlling for age, racial composition, population density, income, and geographic size of SMSA. The most significant pollution variables were the minimum biweekly sulfate and the mean biweekly particulate levels. Increase of 1 $\mu\text{g}/\text{m}^3$ in the former (raising the mean from 4.72 to 5.72 $\mu\text{g}/\text{m}^3$) was associated with an increase of 6.3 per 100,000 in the total death rate, whereas an increase of 10 $\mu\text{g}/\text{m}^3$ in the latter (raising the

mean from 118.1 to 128.1 $\mu\text{g}/\text{m}^3$) was associated with an increase of 4.5 per 100,000 in the total death rate.

A significant relation between daily SO_2 levels and daily mortality in Chicago was found, by Lave and Seskin (in press) in a study of SO_2 , NO, NO_2 , CO, and hydrocarbons in five cities (Chicago, Denver, Philadelphia, St. Louis, and Washington, D.C.). A regression including current and lagged values of SO_2 , three weather factors, and day of the week, associated a decrease of 50 percent in SO_2 level with a decrease of 5.5 percent in daily deaths. A significant relation was found for NO in Chicago. A study by Carnow et al. (1969) in Chicago showed a similar association between mortality from respiratory diseases and SO_2 levels.

An analysis of cause-specific mortality statistics for 42 SMSAs (Sprey et al., 1974) revealed a positive correlation of mortality from arteriosclerotic heart disease and neoplasms of the respiratory and gastrointestinal tracts with sulfate levels. For white males over 65, an increase in median sulfate concentrations from 5 $\mu\text{g}/\text{m}^3$ to 24 $\mu\text{g}/\text{m}^3$ was associated with a 19 percent increase in mortality from arteriosclerotic heart disease.

Glasser and Greenburg (1971) found a definite relationship between deviations from a five-year "normal" in New York City's daily mortality, and daily mean concentration of sulfur dioxide. They used a regression analysis including sulfur dioxide, rainfall, wind speed, sky cover, and temperature deviations as explanatory variables.

Schimmel and Greenburg (1972) regressed daily mortality on sulfur dioxide and smoke shade levels for the same and previous days, while controlling for weather factors and day-of-the-week effects. They concluded that, if air pollution in New York City were reduced to zero, there would be, on the average, from 18.12 to 36.74 fewer deaths each day, depending on the particular pollution variate under consideration. This represents about 12 percent of the over half - million deaths occurring during the six-year study period. Furthermore, in looking at the individual effects of the two pollutants,

they concluded that 80 percent of the excess deaths could be attributed to smoke shade, and only 20 percent to sulfur dioxide.

Buechley et al. (1973) analyzed the relationship between daily mortality and sulfur dioxide levels in the New York-New Jersey metropolitan region between 1962-1966. The analysis controlled for temperature, holidays, day of the week, and epidemics, and eliminated "disasters and time trends". Residual mortality values (observed minus predicted mortality) correlated well with 11 classes of SO_2 concentrations. An increase in concentration from 50 to 1000 $\mu\text{g}/\text{m}^3$ corresponded to a 3 percent increase in residual mortality. Schimmel and Murawski (1975) and Buechley (1975) have recently offered a re-evaluation of their New York City data. Both reach the conclusion that SO_2 was a proxy for some other factor and not the causative agent.

Epidemiologic studies of U.S. EPA's Community Health and Environmental Surveillance System (CHESS) program have provided dose-effect information on morbidity associated with exposure to sulfur dioxide and other air pollutants. Health indicators employed for long-term effects were prevalence of chronic bronchitis in adults, incidence of acute lower respiratory infection in children, acute respiratory illness in families, and decreases in ventilatory functions of children. The short-term indicators were aggravation of cardiopulmonary symptoms and of asthma. The results support the long-term air quality standards, but indicate that the short-term standards may be too high.

The best known epidemiologic studies of the effect of nitrogen dioxide (NO_2) on human health were conducted by Shy et al. (1970a, 1970b) at Chattanooga, Tennessee, where emissions from a chemical factory provided an opportunity to compare incidence of acute respiratory disease in areas of high, intermediate, and low NO_2 levels. The health data covered the period of 1968-1969, but the corresponding NO_2 data, obtained by the Jacobs-Hochheiser technique, were considered unreliable and were replaced by 1967-1968 NO_2 data measured by the Saltzman method (Shy et al., 1973).

Sprey et al. (1974) studied annual data on pollution, climatology, mortality, and socioeconomic characteristics for 42 SMSAs with the aid of single-variable analysis of the median disease-specific mortality rates and found a strong association between NO_2 levels and mortality from hypertensive and arteriosclerotic heart disease and lung cancer. Increases in NO_2 level from 0.3 to 0.8 ppm were associated with approximately 200 more deaths per 100,000 from hypertensive heart disease for white males or females over 65, with 50 and 130 percent increases in lung cancer death rates for white males over 65, and white females over 65, respectively.

A comprehensive survey of health damage studies dealing with carbon monoxide and other automotive pollutants was published two years ago by the National Academy of Sciences-National Academy of Engineering (NAS-NAE, 1974).

Hexter and Goldsmith (1971) found a significant association between daily mortality in Los Angeles County and levels of carbon monoxide, but no significant association between mortality and oxidant levels. An increase in carbon monoxide level from 7.3 ppm (lowest 24-hour basin average observed during the study period) to 20.2 ppm (highest observed) was eleven deaths for that day. Because the analysis was controlled only for temperature, leaving out other possibly relevant factors, the results should be viewed with caution.

A study by Carnow and Meier (1973) of lung cancer mortality in the 48 contiguous United States and in 19 countries concluded that an increase of 1 μg of benzo(a)pyrene in 1000 m^3 of air was associated with an increase of 5 percent in lung cancer mortality. Benzo(a)pyrene levels were estimated on the basis of fuel consumption.

A number of economic studies of air pollution health damages are being pursued by various investigators under the auspices of U.S. EPA's Office of Research and Development. One of these was an analysis of the impact of suspended particulate concentrations on outpatient medi-

cal costs in the Portland, Oregon SMSA by Jaksch and Stoevener (1974), who utilized records of the Kaiser-Permanente Medical Care Program. Numerous covariates, such as age, sex, marital status, income, etc., were included in the regression analysis. The results indicated that an increase in particulate concentration from 60 to 80 $\mu\text{g}/\text{m}^3$ would result in a 3.5 cent increase in expense per medical visit for respiratory diseases.

Another study by the California Air Resources Board (Leung et al., 1975) presents a series of dose-effect functions representing the health effects of oxidants, nitrogen dioxide, and carbon monoxide, developed on the basis of questionnaires completed by a panel of 14 experts. The results are of some interest as an expert consensus, but the most significant outcome was the experts' own assessment that, because of lack of adequate data, their judgment was "not trustworthy" in most cases. This lack of confidence is a salutary reminder that the art of developing dose-effect functions for human health is a long way from being an exact science.

2. Damage Estimates

The current "best estimate" of the 1973 air pollution damages to health is \$5.7 billion. This figure is based on updated results of the work of Lave and Seskin (1973), Waddell (1974), Rice (1966), and U.S. EPA (1974). An explanation of the revisions is provided in the appendix.

The primary basis for estimating damages from mortality and morbidity associated with air pollution is the work of Lave and Seskin (1973), as adapted by Waddell (1974). Although no changes have been made here to the health dose-response relationship, the costs of illness have been substantially revised since the original data were collected in 1963 in accordance with the methodology of the original studies by Rice (1966). These adjustments reflect increases in the cost and level of direct health expenditures, increases in total mortality and morbidity due to population growth, increases in mean earnings,

and better data on the value of housewives' services. No adjustments have been made for changes in demographic patterns, or the age and sex distribution of illness.

According to the findings of Lave and Seskin, the 26 percent reduction of suspended particulates and, by implication, sulfates, required to reach the primary ambient air quality standard, would lower mortality and, presumably, morbidity by 2.3 percent. This would reduce the resultant damages by \$4.6 billion in 1973. If the mortality and morbidity associated with air pollution were 15 percent, as estimated by Sprey and Takacs, rather than 9 percent, then a 26 percent reduction in pollution would result in a 3.9 percent decrease in the national costs of illness. This would make the corresponding 1973 estimate of damages \$7.7 billion.

A more direct evidence of the impact of air pollution and respiratory illness is provided by the CHESS program. The derivation of damage estimates from the CHESS studies was based on the expenses of the additional health symptoms and restricted activity associated with air pollution, adjusted for increases in the price of health care and extrapolated to the population at risk. The resulting estimate places the 1973 damages from selected respiratory morbidity at \$2.5 billion in 1973

If the estimate of \$4.6 billion based on the Lave and Seskin data is adjusted to eliminate the costs from respiratory morbidity included in the CHESS estimates, the new figure is \$3.2 billion. The two estimates then become additive, yielding a total of \$5.7 billion for the benefits of reduced illness resulting from improved air quality.

Recent studies on air quality and automobile emission control by the National Academy of Sciences and the National Academy of Engineering bear out the general magnitude of these estimates. Using data on discomfort from photochemical oxidants and mortality from nitrogen oxides, these studies estimated damages to range from \$360 million to \$3 billion annually. These estimates include only pollutants from automobile emissions.

It is important to point out that these estimates are based only on costs of medical care expenses and forgone earnings or productivity. Such estimates clearly understate the total social value of improved health, because they do not include the value of leisure time lost through illness, of time lost by people who do not receive monetary compensation for their labor (e.g., volunteers, housewives, retirees, children), or of avoiding the discomfort, pain, and anxiety associated with illness.

Moreover, the National Academy of Sciences report assumed the value of life to be \$200,000 based on new studies of the willingness-to-pay for increased life expectancy. Adoption of this figure would elevate the damage estimates based on the Lave-Seskin mortality studies from \$7.7 billion to over \$20 billion.

C. AESTHETIC DAMAGES

Although aesthetic damages are difficult to quantify, they appear here as the largest damage category on the basis of property value studies.

1. Survey of Source Studies

Aesthetic effects may take the form of reduced visibility, irritation of eyes, nose, and throat, or malodors. All of the major pollutants, with the possible exception of carbon monoxide, can contribute to the first problem; ozone, aldehydes, and other components of smog are held accountable for the second; and a host of minor pollutants, including ammonia, hydrogen sulfide, and mercaptans, are responsible for the third. The relationships between pollutant levels and visibility are relatively straightforward. Charlson (1969) derived a rather simple equation relating visibility to aerosol levels, which yielded a correlation coefficient of 0.82 for 238 readings in a variety of locations. Hammer et al. (1974) compared reports of mild respiratory symptoms with oxidant levels in Los Angeles. The effect of malodor as a function of pollutant concentration is much more difficult to measure because of its subjective nature.

The economic impact of these effects has been measured in terms of people's willingness to pay for pollutant abatement leading to a reduction of the offensive condition. This may be accomplished through public opinion surveys, or through studies of changes in property values as a function of air pollution levels. For example, Mason (1973) and Vars and Sorenson (1973) surveyed the opinion of tourists on heavy smoke problems in the Willamette Valley in Oregon caused by the burning of grasses.

Randall et al. (1974) carried out a series of so-called bidding games designed to assess willingness to pay for abatement of particulate emissions among several population subgroups in the Four Corners area in the Southwest. A questionnaire was administered to local residents and tourists after they had viewed three sets of photographs, each showing the aesthetic aspects of different levels of pol-

lution. The bidding process was designed to determine the maximum amounts that households would be willing to pay for improvements shown in the photographs. The realistic payment mechanisms included sales taxes, electricity bills, monthly payments, user fees, and compensation for environmental damages.

A summary of the property value studies of primary interest in developing national estimates of the aesthetic damages of air pollution is shown in Table II-3. These studies employed multiple regression techniques and several measures of pollution levels and property values. All found an inverse relationship between pollution levels and property values.

Table II-3. Listing of Property Value Studies

Investigator	Date	Location	Pollution Measure
Ridker-Henning	1967	St. Louis	Sulfation*
Zerbe	1969	Toronto	Sulfation
		Hamilton	Sulfation
Anderson-Crocker	1970	St. Louis	Sulfation Suspended particulate
		Kansas City	Sulfation Suspended particulate
		Washington, D.C.	Sulfation Suspended particulate
Crocker	1971	Chicago	Sulfur dioxide Suspended particulate
Peckham	1970	Philadelphia	Sulfation Suspended particulate
Spore	1972	Pittsburgh	Sulfation Dustfall
NAS and NAE	1974	Boston and Los Angeles	Nitrogen oxides and Particulates
Nelson	1975	Washington, D.C.	Oxidants

(*) A measure of SO₃ deposition, probably also indicative of particulate levels

2. Damage Estimates

The measurement of the aesthetic damages of air pollution is complicated by the indirect ways in which aesthetics influence market transactions. Yet, because people seem to be more aware of the aesthetic impacts of air pollution than its health impacts, it is reasonable to assume that such an awareness will be, in some way, reflected in their behavior.

The aesthetic damages from air pollution estimated using the property value approach are \$9.7 billion annually. This estimate has been based primarily on a series of property value studies performed at various times and places throughout the country, and synthesized by Waddell (1974). The more recent study by the National Academy of Sciences and the National Academy of Engineering (1974), provides general support for these figures by an estimated range of \$1.5 billion to \$5 billion for automotive pollutants class.

The studies indicate that, in 1970, the marginal damage from sulfur oxides that was capitalized in the residential property market fell in the range of \$100 to \$600 for a decrease of 0.1 mg $\text{SO}_3/100 \text{ cm}^2$ per day. An estimate of \$8.9 billion was developed by considering the mean sulfur dioxide concentrations for all metropolitan areas and the number of housing units in each. The annual average return on real property wealth was computed using a 10 percent discount rate. The 1970 estimates have been updated for this report to reflect the increase in urban housing units and the growth and inflation of the economy.

A recent study has addressed the relationship between property values and oxidant levels due to automotive air pollution in Washington, D.C. (Nelson, 1975). The study concludes that the reduction in damages reflected in nationwide property values from a 45 percent reduction in oxidant concentration would be \$0.8 billion. Adding the \$0.8 billion for oxidants to the 98.9 billion for sulfur dioxide and particulates gives a total of \$9.7 billion as the best estimate of the aesthetic damages of air pollution, as reflected in property values.

Although wage differential studies give similar results, it is clear that they measure some of the same phenomena as property value differences. Since the two techniques are so closely linked, addition of their results would constitute double counting. The property value studies have been used here, because they provide a more extensive and less ambiguous basis for damage estimation.

These property value studies underestimate total aesthetic damages, because they address only residential property in urban areas. The bidding game study conducted by Randall et al. (1974), near Farmington, N.M., could provide the rural component. The study estimated that local households would be willing to pay \$50 annually for a 73 percent reduction in particulate emissions. This corresponds to \$0.9 billion on the national basis. However, this component has been omitted from the reported total estimate, because of suspected response bias and the uncommon nature of the local situation.

D. DAMAGES TO VEGETATION

The effects of air pollutants on crops and ornamental plants have been the subject of numerous, but inconsistent, investigations. Recent discovery of high oxidant levels in such areas indicates potential crop damages much higher than had been estimated in the past.

1. Survey of Source Studies

The major air pollutants implicated in damage to vegetation are sulfur oxides, oxidants, nitrogen oxides, acid rain (a mixture of sulfuric, nitric, and hydrochloric acids), and fluorides. Effects of air pollutants on vegetation exhibit wide variations among the various species and as a result of differing genetic and environmental conditions. The latter include stage of growth, general viability and vigor, temperature, humidity, amount of insolation, soil moisture and acidity, and availability of nutrients. These are much more important here than in the case of human health effects, where the target population belongs to one species and genetic and environmental conditions are controlled within a more narrow range.

Determination of effects has been based largely on measurement of the extent of leaf injury and several indices were developed relating this measure to yield loss. Leaf injury is still considered an important indication of effect in certain plants, such as lettuce and tobacco, because leaf appearance affects saleability. However, substantial losses of fruit, grain, and timber have been found even in the absence of significant leaf injury, so the latter can no longer serve as an indiscriminate proxy for yield loss. An additional undetermined amount of yield loss occurs when more resistant plant varieties are substituted for the more susceptible ones, which tend to be more productive.

Concern over air pollution damage to vegetation has received renewed impetus from the recent discovery of heretofore unsuspected high oxidant levels in rural areas and the completion of investigations indicating substantial crop losses at these levels. However, the determination of response of crops and forests has been severely handicapped

by the virtual lack of monitoring stations in rural areas. Consequently, ambient levels had to be estimated on the basis of daring interpolations between readings at distant stations or occasional measurements with the aid of portable instruments.

Moreover, past investigations were designed primarily to determine susceptibilities of individual plant varieties, rather than to establish a broadly applicable relationship between dose and effect. Consequently, there has been relatively little interest in coordinating the research effort or in setting uniform standards and conditions of investigation that would permit some aggregation or comparison of the results of different studies.

Early studies identified sulfur dioxide as the primary factor in air pollution damage to vegetation, and many of these developed quantitative relationships between SO_2 levels and plant injury or yield loss. More recent investigations have examined the effects of acid rain and mist, as well as oxidants, nitrogen dioxide, and fluorides.

Exposure of ryegrass to sulfur dioxide in coal smoke was found to reduce plant weight between 16 and 57 percent (Bleasdale, 1973). Earlier leaf senescence was also observed in plants exposed to ambient SO_2 . The reliability of the SO_2 data is in question due to the imprecise measurement of ambient pollutants. Moreover, the coal smoke may well contain various particulate fractions capable of producing damage.

Sulfur dioxide effects on soybeans have been investigated by David (1972) in a three-year study involving 485 soybean plots. Good correlation was found between leaf area destroyed and reduction of yield.

Ornamental species were fumigated with SO_2 in controlled environment chambers by Temple (1973). Three-dimensional dose-response curves similar to those of Heck were constructed for each species. Damages to foliage of up to 95 percent were found at concentrations of $11 \mu\text{g}/\text{m}^3$ (4 ppm) for 6 hours.

Hill et al. (1974) investigated the effects of SO_2 and NO_2 on about 80 native desert species in Utah and New Mexico. Fumigation levels of SO_2 ranged from $1430 \mu\text{g}/\text{m}^3$ (0.5 ppm) to $25,600 \mu\text{g}/\text{m}^3$ (10 ppm). Most species showed a marked injury increase at either 6 or 10 ppm. No synergistic effects of SO_2 and NO_2 were found at these levels.

On the other hand, distinct synergistic effects were observed upon exposure of tobacco to acute fumigations with SO_2 and O_3 (Menser and Heggestad, 1966). Three cultivars of tobacco showed no leaf damage upon exposure to 2-4 hours of 0.03 ppm O_3 levels and 0.24 ppm SO_2 . However, when these concentrations were used together, 38 percent of the leaf area suffered damage after a 2-hour fumigation and 75 percent after a 4-hour fumigation.

The first major crop plant to be investigated for oxidant damage was the experimental and highly susceptible Bel W-3 tobacco cultivar. Heck et al. (1966) showed that varying exposures of up to 60 ppm of ozone for four hours may cause more than 90 percent leaf injury. The results were plotted in a three-dimensional surface representing an injury index as a function of both exposure time and concentration.

Turner et al. (1972) assessed directly ozone damage to tobacco by measuring height, dry weight, leaf area, amount of fleck injury, as well as total leaf stomatal conductance, an indirect measure of photosynthesis, and respiration. Four cultivars of varying sensitivity were grown under field conditions during both years of the study and in greenhouses during the second year. The uninjured leaf area for the most tolerant (6524) and the most sensitive (Bel W-3) cultivars was determined to be 10 and 71 percent, respectively, in the presence of ozone, and 10 and 14 percent, respectively, in filtered air.

The predisposition to injury from previous exposure was investigated by Heagle and Heck (1974), again for the Bel W-3 cultivar. Plants exposed to seven days of continuous high oxidant levels ex-

hibited more than twice as much injury as the total of seven plants exposed for only one day each. The postulated mechanisms for the cumulative injury are progressive accumulations of toxic substances, progressive degradation of cell membranes, or a gradual disruption of enzyme processes. The eight week mean total injury per leaf indices were found to be twice as high for continuous groups as for daily exposure groups.

In a similar set of experiments, Heck and Tingey (1971) obtained acute injury indices as a function of exposure time and concentration for a number of crop and ornamental plants. The plants were exposed to .075 - 1.0 ppm ozone levels for periods of up to seven hours.

Heggestad (1973) reported on yield losses for a number of potato cultivars. Some of these suffered up to 50 percent reduction in yield upon exposure to oxidant levels above 0.05 ppm.

Effects of oxidant exposure on cotton yield in the San Joaquin Valley were studied during a two-year period in four locations by Brewer and Ferry (1974). Cotton grown in filtered air was found to produce 10-30 percent more yield than control plants grown in chambers containing unfiltered air or those grown on the outside.

Effects on corn yield were studied in New England (Feder, 1972) and in California (Thompson, 1975). Feder found that corn exposed to pollutant levels of approximately 0.10 ppm for seven hours per day, five days per week, suffers a reduction of 30 percent in leaf area, 20 percent in stem length, 32 percent in ear weight, and 60 percent in number of filled kernels per year. Thompson reported significant yield reductions for two cultivars of corn. In the case of Monarch Advance, a susceptible variety, fresh weight per husked ear was reduced by 28 percent by exposure to ambient smog over the growing season. For Bonanza corn, a more resistant variety, ear weight was only slightly affected, but the number of second ears was reduced by 75 percent when compared with plants grown in filtered air.

Thompson (1975) also found major reductions in plant weight of up to 50 percent for spinach, 62 percent for radish, and 58 percent for lettuce grown under varying concentrations of photochemical smog.

The yield of lemons has been found to be significantly affected by ambient smog, but the effect of component pollutants could not be separated (Thompson and Taylor, 1969). In a similar fashion, exposure of navel orange trees to both ozone and peroxyacetyl nitrate have shown that ozone alone causes little damage, but peroxyacetyl nitrate and photochemical smog produce significant increases in fruit drop.

The most extensive survey of the effects of oxidants on coniferous trees has been performed by Davis and Wood (1972). The study focused on leaf injury to new growth in 2-6 year-old seedlings, which may affect the photosynthesis process, and hence, the eventual growth of the trees. Six species of pine (*Pinus*), two of larch (*Larix*), and eastern hemlock (*Tsuga canadensis*) were found to be susceptible to 8-hour exposures to 0.25 ppm ozone levels every two weeks. Nine other coniferous species including four spruce (*Picea*), two fir (*Abies*), Douglas fir (*Pseudotsuga menziesii*), *Aborvitae* (*Tsuga occidentalis*), and red pine (*Pinus resinosa*) were found to be resistant to damage at these levels.

Threshold levels of foliar injury and yield reduction due to exposure to fluorides have been charted by McCune (1969) for conifers, corn, gladiolas, sorghum, tomato, and tree fruits. His results show that even between such diverse plant types as tomato and conifers, threshold levels for any particular length of exposure fall within a factor of ten and they are much closer for other plants. More detailed information on the individual species has been reported by the National Academy of Sciences (NAS, 1971). Relations between fumigation levels and total fluoride content has been derived for alfalfa and a number of other forage crops.

2. Damage Estimates

The estimated damages by air pollutants to vegetation in 1973 are \$2.9 billion. This amount reflects the application of new data on rural oxidant levels and results of yield loss experiments. The detailed breakdown of this estimate is given in Table II-4.

Table II-4. Estimated Air Pollution Damage to Vegetation

Pollutant	Vegetation Type	Damage (\$ billion)
Oxidants	Crops	2.8
	Ornamentals	0.09
Sulfur dioxide and acid rain	Forests	0.01
Fluorides		<u>0.01</u>
		2.9

The oxidant damage to crops was estimated by multiplying the average yield losses corresponding to prevailing rural oxidant levels by the 1973 value of crops in those regions, where high oxidant concentrations were suspected. The other values were obtained by updating Benedict's (1973) estimates, to the year 1973. The detailed calculations are presented in the Appendix.

It should be noted that several types of damages are not included here, because of the difficulty of assigning a monetary value. These are the effect of reduction in insolation due to absorption by atmospheric particulates, the effect of acid rain and other pollutants on plant foliage and growth, and the cost of developing pollution resistant plant varieties.

Although the total damage estimate is probably conservative from the perspective of assumed yield losses, it is important to recognize that the actual market response to increased yields resulting from decreased air pollution is difficult to determine without a detailed analysis. In a free market, increased yield, with the resultant lowering of the unit cost of production, can be expected to reduce prices and to increase output and consumption somewhat.

The achievement of agricultural benefits is also heavily dependent on government policies, such as price supports, production quotas, and import-export regulations. During periods of agricultural surplus, with government price supports, there is less national benefit from yield increases. However, in times of shortages, yield increases can produce substantial benefits.

E. DAMAGES TO MATERIALS

Investigations of the effects of air pollutants on materials are less complicated than those of health or vegetation effects, because of the opportunity to control both exposure and the target population. Nevertheless, there have been few useful damage studies in this area.

1. Survey of Source Studies

Sulfur oxides in the presence of moisture and oxidants, probably in the form of sulfuric acid, have been found responsible for the corrosion of metals, damage to electrical contacts, deterioration of paper, textiles, leather, finishes and coatings, and erosion of building stone through conversion of calcium carbonate to the soluble sulfate. The major effects of particulate exposure on materials are the soiling and deterioration of painted and other exposed surfaces. Degradation of painted surfaces may take the form of chalking, cracking, erosion, flaking, or changes in the color or tensile strength of paints. Ozone shortens the life of rubber products, dyes, and paints. Nitrogen oxides also cause fading of dyes and paints.

Investigations of the effects of air pollutants on materials provide the opportunity to control both exposure and the makeup of the target population. Nevertheless, useful damage studies in this area are few, largely confined to representations of the corrosion of metals by sulfur oxides and the soiling of exposed surfaces by particulates. Other pollutants studied include particulates, nitrogen oxides, and oxidants. Target materials are paper, textiles, leather, paints and dyes, rubber, plastics, metals, ceramics, and stone.

Effects of long-term exposures have been determined by exposing test panels to ambient conditions for long periods of time. The results of these field studies have been flawed by poor ambient level measurements and failure to account for other pertinent environ-

mental variables. Laboratory studies have attempted to determine short-term effects by subjecting test panels to elevated pollutant concentrations. Recent laboratory experiments have employed more realistic concentrations. Humidity exerts a major influence on the severity of most effects, with temperature and air flow playing lesser roles.

Haynie and Upham (1971) exposed three types of steel at eight urban sites to determine the effect of sulfur dioxide, nitrogen oxide, and oxidant exposures on corrosion of the metal. They found that corrosion increased with higher SO_2 levels, but decreased with rising oxidant concentrations, which apparently acted antagonistically toward sulfur dioxide. In the same experiment, Haynie and Upham (1970) exposed test samples of zinc in eight urban areas and found a linear relationship between corrosion rate and an atmospheric factor composed of SO_2 concentration and relative humidity.

The frequency of maintenance of painted surfaces exposed to particulates was investigated in Philadelphia (Booz, Allen and Hamilton, Inc., 1970) and in five other towns and suburbs (Michelson and Tourin, 1967). The results of the two studies are in sharp disagreement, because responses in the five cities record substantial increase in maintenance frequency with particulate concentration, whereas the Philadelphia study found no significant differences. One reason for the discrepancy may be the covariation of income and attitude towards maintenance with air pollution levels in the Philadelphia study.

Beloin and Haynie (1973) investigated the relationship between particulate concentration and rate of soiling for painted surfaces, as well as cedar siding, asphalt shingles, concrete blocks, limestone, brick, and window glass, at five test sites in Birmingham, Alabama. The materials were exposed to ambient suspended particulates at levels between 60-260 $\mu\text{g}/\text{m}^3$ over a two-year period. Soiling was expressed in terms of reflectance measurements for opaque surfaces and in terms of haze measurements

for glass. The degree of soiling of painted cedar siding was found to be proportional to the square root of the particulate exposure, whereas the degree of soiling for shingle siding was directly proportional to the exposure. However, the soiling of limestone, concrete, brick, and glass surfaces exhibited no clear correlation with particulate exposure.

The most comprehensive survey of economic losses incurred to materials due to air pollution was compiled by Salmon (1970). He estimated a general economic loss of \$3.8 billion by examining damages to 32 material categories. The pollutants in decreasing order of economic importance were found to be sulfur oxides, ozone, nitrogen oxides, carbon dioxide and particulates. Waddell (1974) has combined parts of this study with in-depth analyses of cost of materials losses in 1970.

Haynie (1974) has assessed economic damages to metals, paints, elastomers, electrical contacts and electronic components at \$2.7 billion per year. The percentages of total economic loss and available reference material are given for metals, paints, textiles, elastomers, and plastics. Each area is also rated as to whether there is strong or weak evidence of damage or only a suspected relationship.

Economic damage from sulfur dioxide has been estimated by Gillette (1974), both on a national and regional basis. Damages due to SO_2 were estimated to decrease from \$900 million to \$75 million over a five-year time period which saw reductions in national SO_2 levels.

2. Damage Estimates

The materials damages attributed to air pollution in 1973 have been estimated to be \$1.9 billion. This estimate emerges from the synthesis of many studies by Waddell (1974), as adjusted to reflect inflation to 1973 (see Table II-4). More recent studies have focused on such materials as aluminum, zinc and structural steels, building materials, paints, vinyl and acrylic coil coatings, drap-

ery, and automotive finishes. The findings of these studies support the estimates in Table II-5, but provide little basis for additional estimates.

Table II-5. Materials Damage Estimates

Material	Source	1973 Damages (\$ billion)
General materials*	Salmon (1970)	0.5
	Gillette (1973)	0.5
	Mueller and Stickney (1970)	0.6
Dyes	Salvin (1970)	0.2
Paints	Spence and Haynie (1972)	<u>0.2</u> **
		1.9***

*Adjusted to eliminate overlap with other materials damage estimates.

**Adjusted to eliminate overlap between residential painting and property value damages.

***Values do not add up because of rounding.

The above figures do not reflect fully all material damages experienced by society. In many cases, there are additional avoidance costs to develop new materials more resistant to attack by air pollution. These new materials are likely to be more expensive than those more susceptible to damage. Society also bears the costs of cleaning and repairs, including the replacement of failed or deteriorated components and structures. In some cases, the failure of a material can itself cause damages.

F. MORE ELUSIVE DAMAGES

As was pointed out on repeated occasions, the current state-of-the-art in damage assessment does not permit full estimation of all the damages associated with air pollution. For example, in assessing the damages to human health, the value of lost leisure time and psychic costs are not adequately reflected in estimates of the economic cost of illness. Other important conclusions were cited in the case of damages to vegetation and materials.

In addition, several large damage categories were not ever considered in this study, because of lack of an adequate data base or the great difficulty of quantifying the damages. These categories include:

- Meteorological and climatic damages
- Contamination of soil and surface water
- Disruption of ecosystems
- Damages to animal health.

Air pollutants have been found to cause either increases or decreases in precipitation, depending on local meteorological and topographic conditions. There is also a definite relationship between atmospheric dust level, contributed principally by volcanic eruptions, and the drop in mean temperature of the earth's atmosphere. This has potentially great importance, because a 1.6 percent decrease in the amount of solar radiation reaching the earth has been estimated to be capable of producing severe glaciation.

Investigations of the contribution of air pollutants to the contamination of surface waters and soil have been conducted on Lake St. Claire, on Lake Michigan, in the Sierra Mountains, and in England.

REFERENCES

- Anderson, R. J., and T. D. Crocker, Air Pollution and Housing: Some Findings, Prudue University, 1970.
- Beloïn, N. J., and F. H. Haynie, Soiling of Building Materials, U.S. Environmental Protection Agency, January 1973.
- Benedict, H. M., et al., Assessment of Economic Impact of Air Pollution on Vegetation in the United States - 1969 and 1971, Stanford Research Institute, July 1973.
- Bleasdale, J. K., "Effects of Coal-Smoke Pollution Gases on the Growth of Ryegrass," Environ. Pollut. 5: 275-285, 1973.
- Booz, Allen and Hamilton, Inc., Study to Determine Residential Soiling Costs of Particulate Air Pollution, National Air Pollution Control Administration, Raleigh, N.C., October 1970.
- Brewer, R. F., and G. Ferry, "Effects of Air Pollution on Cotton in the San Joaquin Valley," Calif. Agric., pp. 6-7, June 1974.
- Buechley, R. W., et al., "SO₂ Levels and Perturbations-in Mortality: A Study in the New York-New Jersey Metropolis," Arch. Environ. Health 27: 134-135, 1973.
- Buechley, R. W., SO₂ Levels, 1967-1972, and Perturbations in Mortality: A Further Study in the New York-New Jersey Metropolis, National Institute of Environmental Health Sciences, August 1975.
- Carnow, B. W., et al., "Chicago Air Pollution Study: SO₂ Levels and Acute Illness in Patients with Chronic Bronchopulmonary Disease," Arch. Environ. Health 18: 768-776, 1969.
- Carnow, B. W., and P. Meier, "Air Pollution and Pulmonary Cancer," Arch. Environ. Health 27: 207-218, 1973.
- Costonis, A. C., and W. A. Sinclair, "Ozone Injury to Pinus Strobus," J. Air Pollut. Control Assoc. 19: 867-871, 1969.
- Crocker, T. D., Urban Air Pollution Damage Functions: Theory and Measurement, Environmental Protection Agency, 1971.
- Davis, C. R., "Sulfur Dioxide Fumigation of Soybeans: Effect on Yield," J. Air Pollut. Control Assoc. 22: 778-780, 1972.
- Davis, D. D., and F. A. Wood, "The Relative Susceptibility of Eighteen Coniferous Species to Ozone," Phytopathology 62: 14-19, 1972.
- Feder, W. A., "Plant Response to Chronic Exposure of Low Levels of Oxidant Type Air Pollution," Environ. Pollut. 1: 73-79, 1970.
- Feder, W. A., "Cumulative Effects of Chronic Exposure of Plants to Low Levels of Air Pollutants," in John A. Naegel, Air Pollution Damage to Vegetation, American Chemical Society, Washington, D.C., 1972.

Gillette, G., Sulfur Dioxide Standards and Materials Damage, Environmental Protection Agency, 1974.

Glasser, M., and L. Greenburg, "Air Pollution, Mortality, and Weather," Arch. Environ. Health 22: 334, 1971.

Haynie, H., "The Economics of Clean Air in Perspective," Materials Performance, 13(4): 33-38, April 1974.

Haynie, F. H., and J. B. Upham, "Effects of Atmospheric Sulfur Dioxide on the Corrosion of Zinc," Mater. Prot. Perform. 9: 35-40, 1970.

Haynie, F. H., and J. B. Upham, Effects of Atmospheric Pollutants on Corrosion Behavior of Steels, U.S. Environmental Protection Agency, December 1971.

Heagle, A. S., and W. W. Heck, "Predisposition of Tobacco to Oxidant Air Pollution Injury by Previous Exposure to Oxidants," Environ. Pollut. 7: 247-251, 1974.

Heck, W. W., et al., "Ozone: Non-Linear Relation of Dose and Injury in Plants," Science 151: 577-578, 1966.

Heck, W. W., and D. T. Tingey, "Ozone, Time-Concentration Model to Predict Acute Foliar Injury," pp. 249-255, in Proceedings of the Second International Clean Air Congress 1971.

Heggestad, H. G., "Photochemical Air Pollution Injury to Potatoes in the Atlantic Coastal States," Am. Potato J. 50: 315-328, 1973.

Hexter, A. C., and J. R. Goldsmith, "Carbon Monoxide: Association of Community Air Pollution with Mortality," Science 172: 265, 1971.

Hill, C. A., et al., "Sensitivity of Native Desert Vegetation to SO_2 and to SO_2 and NO_2 Combined," J. Air Pollut. Control Assoc. 24: 153-157, 1974.

Howell, Unpublished study on soybean yields and ambient ozone exposure, U.S. Department of Agriculture, College Park, Maryland, 1973-1974.

Jaksch, J. A., Outpatient Medical Costs Related to Air Pollution in the Portland-Vancouver Area, Unpublished Ph.D. Dissertation, Oregon State University, Corvallis, Ore., 1973.

Lave, L. B., and E. P. Seskin, "An Analysis of the Association Between U.S. Mortality and Air Pollution," J. Amer. Stat. Assoc. 68: 284-290, 1973.

Lave, L. B., and E. P. Seskin, Air Pollution and Human Health, Johns Hopkins University Press, Baltimore, Md. (in press).

Leung, S., E. Goldstein, and N. Dalkey, Human Health Damages from Mobile Source Air Pollution: A Delphi Study, State of California Air Resources Board, March 1975.

- Mason, R. G., "Effects of Air Pollution on Public Attitudes and Knowledge," Oregon State University, June 1972.
- Menser, H. A., and H. E. Heggstad, "Ozone and Sulfur Dioxide Synergism Injury to Tobacco Plants," Science 151: 424-425, 1966.
- Michelson, I., and B. Tourin, Report on Study of Validity of Extension of Economic Effects of Air Pollution Damage from Upper Ohio River Valley to Washington, D.C. Area, Environmental Health and Safety Research Association, August 1967.
- Mueller, W. J., and P. B. Stickney, A Survey and Economic Assessment of the Effects of Air Pollution on Elastomers, U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, June 1970.
- National Academy of Sciences, National Academy of Engineering, Air Quality and Automobile Emission Control, U.S. Government Printing Office, 1974.
- National Academy of Sciences, Fluorides, Washington, D.C., 1971.
- Nelson, J. P., Effects of Mobile-Source Air and Noise Pollution on Residential Property Values, U.S. Department of Transportation, 1975.
- Peckham, B. W., Air Pollution and Residential Property Values in Philadelphia, U.S. Department of Health, Education, and Welfare, 1970.
- Randall, A., et al., Benefits of Abating Aesthetic Environmental Damage from the Four Corners Power Plant, Fruitland, New Mexico, New Mexico State University, Agricultural Experiment Station, Bulletin 618, May 1974.
- Rice, D., Estimating the Cost of Illness, Health Economics Series Number 6, U.S. Public Health Service, 1966.
- Ridker, R. G., and J. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," Review of Economics and Statistics 49: 246-257, 1967.
- Salmon, R. L., Systems Analysis of the Effects of Air Pollution on Materials, U.S. Department of Health, Education, and Welfare, 1970.
- Salvin, J. S., Survey and Economic Assessment of the Effects of Air Pollution on Textile Fibers and Dyes, U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, June-1970.
- Schimmel, H., and L. Greenburg, "A Study of the Relation of Pollution to Mortality," J. Air Pollut. Contr. Assoc. 22: 607, 1972.
- Schimmel, H., and T. J. Murawski, "SO₂-Harmful Pollutant or Air Quality Indicator?", J. Air Pollut. Contr. Assoc. 25: 739-740, 1975.
- Shy, C. M., et al., "The Chattanooga School Children Study, Effects of Community Exposure to Nitrogen Dioxide, Part I," J. Air Pollut. Contr. Assoc. 20: 539, 1970a.

Shy, C. M., et al., "The Chattanooga School Children Study, Effects of Community Exposure to Nitrogen Dioxide, Part II," J. Air Pollut. Contr. Assoc. 20: 582, 1970b.

Shy, C. M., et al., Re-Evaluation of the Chattanooga School Children Studies and the Health Criteria for NO₂ Exposure, In-house Technical Report, U.S. Environmental Protection Agency, Research Triangle Park, N.C., March 1973.

Sprey, P., et al., Health Effects of Air Pollutants and Their Interrelationship, U.S. Environmental Protection Agency, 1974.

Spore, R. L., Property Value Differentials As a Measure of the Economic Costs of Air Pollution, Pennsylvania State University, 1972.

Temple, P. J., "Dose Response of Urban Trees to Sulfur Dioxide," J. Air Pollut. Contr. Assoc. 22: 271-274, 1972.

Thompson, C. R., Statewide Air Pollution Research Center, Riverside, Calif., private communication, February 1975.

Thompson, C. R., and O. C. Taylor, "Effects of Air Pollutants on Growth, Leaf Drop, Fruit Drop, and Yield of Citrus Trees," Environ. Sci. Technol. 3: 934-940, 1969.

Turner, N. C., et al., "Stomatal Conductance, Fleck Injury, and Growth of Tobacco Cultivars Varying in Ozone Tolerance," Phytopathology 72: 63-67, 1972.

U.S. Environmental Protection Agency, Office of Research and Development, Health Consequences of Sulfur Oxides: A Report from CHES, 1970-1971, National Environmental Research Center, Research Triangle Park, N.C., EPA-650/1-74-004, May 1974.

Vars, C. R., and G. W. Sorenson, Study of the Economic Effects of Changes in Air Quality, Oregon State University, June 1972.

Waddell, T. E., The Economic Damages of Air Pollution, U.S. Environmental Protection Agency, May 1974.

APPENDIX. CALCULATION OF AIR POLLUTION DAMAGES

This appendix describes the specific data sources and techniques used to develop and update damage estimates for 1973.

1. Calculation of Air Pollution Damages to Health

The estimates for damages of -improved health due to air pollution control were computed following Waddell (1974) from two basic sources:

- Lave and Seskin (1970, 1974), using Rice's Estimating the Cost of Illness (1966)
- CHES (1974).

The computations began with the estimates for 1970 from Waddell and made a series of multiplicative adjustments to account for changes in the basic data from 1970 to 1973. In the case of the cost of illness figures, adjustment factors were computed for the 1963 to 1973 changes. Although adjustments were made as comprehensive as possible, it was not within the available resources to completely recompute some of the more complex analyses performed by Rice. The damage estimate of 2.3 percent of the morbidity and mortality derived from Lave and Seskin was used in conjunction with the 1973 estimate of the total costs of illness to produce the total damage estimate.

The table below summarizes the adjustments in the costs of illness from 1963 to 1973. The individual adjustment factors and the data sources are summarized in subsequent notes keyed to the 1973 estimates.

Summary of Costs of Illness 1963 and 1973 (in billions of dollars)		
	<u>1963</u>	<u>1973</u>
Direct Costs of Health Care	34.2	94.1
Indirect Costs of Morbidity	21.0	38.8
Indirect Costs of Mortality	<u>40.6</u>	<u>65.7</u>
Total Costs of Illness	95.8	198.6

Computations and Data Sources for Direct Costs of Health Care:

Statistical Abstract of the United States, 1974 (hereafter abbreviated SA74), Table No. 99. Data used directly. No computation necessary.

Computations and Data Sources for Indirect Costs of Morbidity:

Adjustments to indirect costs of morbidity were computed for each of the major categories as shown below:

Costs in Billions of Dollars			
<u>Category</u>	<u>1963 Costs</u>	<u>Adjustment Factors</u>	<u>1973 costs</u>
Noninstitutionalized population:			
Males, employed	7.2	$1.01^a \times 1.36^b \times 1.12^c$	11.1
Females, employed	2.6	$1.22^d \times 1.43^e$	4.5
Males, unable to work	4.8	$1.25^f \times 1.52^g$	9.1
Females, unable to work	0.5	$1.88^h \times 1.43^i$	1.3
Females, keeping house	0.9	$1.00^j \times 2.23^k \times 1.17^l$	2.3
Institutionalized population:			
Males	3.2	$1.30^m \times 1.52^n$	6.3
Females	<u>1.9</u>	$1.56^o \times 1.43^p$	<u>4.2</u>
	21.1		38.8

a. Adjustment for change in male workdays lost.

$$\frac{1973 \text{ workdays lost, male}}{1963 \text{ workdays lost, male}} = \frac{263,994}{245 \times 1068.7} = 1.01$$

1973 data source: Current Estimates from the Health Interview Survey, United States - 1973, Series 10, No. 95, Table 16., U.S. Department of Health, Education and Welfare, October 1974 (hereafter Current Estimates, 1973).

1963 data source: Rice (1965), pages 40 and 46.

b. Adjustment for change in male mean earnings.

$$\frac{1973 \text{ mean annual earnings, male}}{1963 \text{ mean annual earnings, male}} = \frac{9,420}{6,949} = 1.36$$

1973 data source: Current Population Reports: Consumer Income, Series P-60, No. 97, Table 61, Department of Commerce, January 1975 (hereafter Consumer Income).

1963 data source: Rice (1966), page 14.

c. Adjustment to 1973 mean earnings for supplements to wages and salaries to parallel adjustment for 1963 made by Rice.

$$\frac{\text{Salary and wages + proprietors income + supplements}}{\text{Salary and wages + proprietors income}} = \frac{691,620 + 96,089 + 94,363}{691,620 + 96,089} = 1.12$$

data source: Survey of Current Business, Vol. 54, No. 7, Table 1.10, U.S. Department of Commerce, July 1974.

d. Adjustment for change in female workdays lost.

$$\frac{1973 \text{ workdays lost, female}}{1963 \text{ workdays lost, female}} = \frac{187,435}{245 \times 626.9} = 1.22$$

1973 data source: Current Estimates, 1973, Table 16.

1963 data source: Rice (1966), pages 40 and 46.

e. Adjustment for change in female mean earnings.

$$\frac{1973, \text{ mean annual earnings, female}}{1963, \text{ mean annual earnings, female}} = \frac{5,134 \times 1.12}{4,027} = 1.43$$

1973 data sources: Consumer Income and Survey of Current Business, July 1974.

1963 data sources: Rice (1966), page 14.

f. Adjustment for change in losses of males unable to work.

$$\frac{1973 \text{ unable to work losses}}{1963 \text{ unable to work losses}}$$

$$= \frac{1973 \text{ males unable to work}}{1963 \text{ males unable to work}} \times \frac{1973 \text{ male labor participation}}{1963 \text{ male labor participation}}$$

$$= \frac{1,299}{1,101} \times \frac{82.9}{78.3} = 1.25$$

data sources: Household Data, Annual Averages,
Bureau of Labor Statistics, Table 1.

Unpublished Data, Bureau of Labor Statistics
SA74, Table No. 543
Rice (1966) pp. 14, 41 and 48.

g. Adjustment for mean annual earnings per notes b and c.

h. Adjustment for change in losses of females unable to work.

$$\frac{1973 \text{ unable to work losses}}{1963 \text{ unable to work losses}}$$

$$= \frac{1973 \text{ females unable to work}}{1963 \text{ females unable to work}} \times \frac{1973 \text{ female labor participation}}{1963 \text{ female labor participation}}$$

$$= \frac{1,065}{699} \times \frac{44.2}{35.9} = 1.88$$

data sources: Household Data, Table 1.
Unpublished Data, Bureau of Labor Statistics
SA74, Table No. 543
Rice (1966) p. 14

i. Adjustments for mean annual earnings per note e.

j. Adjustment for changes in females keeping house.

$$\frac{1973 \text{ females keeping house}}{1963 \text{ females keeping house}} = \frac{35,218}{35,135} = 1.00$$

data sources: Household Data Table 1.
Rice (1966) p. 14

- k. Adjustment for improved data on value of housewives services, 1971.

$$\frac{1971 \text{ value of housewives services}}{1963 \text{ value of housewives services}} = \frac{5,960}{2,670} = 2.23$$

data sources: The Dollar Value of Household Work,
Kathryn E. Walker and William H. Gavager,
Cornell University. Table 4 (average for
2 children families weighted by years
per age interval).

Rice (1966) p. 14.

- l. Adjustment for increase in female earnings since 1971.

$$\frac{1973 \text{ value of housewives services}}{1971 \text{ value of housewives services}} = \frac{1973 \text{ weekly earnings, female}}{1971 \text{ weekly earnings, female}}$$

$$= \frac{117}{100} = 1.17$$

data source: SA74, Table No. 570.

- m. Adjustment for change in institutionalized male population.

$$\frac{1969 \text{ institutionalized population, male}}{1964 \text{ institutionalized population, male}} = \frac{251,900}{193,800} = 1.30$$

data source: SA74, Table No. 127.

- n. Adjustment for mean annual earnings per note g.

- o. Adjustment for change in institutionalized female population.

$$\frac{1969 \text{ institutionalized population, female}}{1964 \text{ institutionalized population, female}} = \frac{563,300}{360,200} = 1.56$$

data source: SA74, Table No. 127.

- p. Adjustment for mean annual earnings per note e.

Computations and Data Sources for Indirect Costs of Mortality:

Adjustments to indirect costs of mortality were computed separately for males and females as shown below:

Costs in Billions of Dollars			
<u>Sex</u>	<u>1963 Costs</u>	<u>Adjustment Factors</u>	<u>1973 costs</u>
Male	26.6	$1.07^a \times 1.52^b$	43.3
Female	<u>14.1</u>	$1.11^c \times 1.43^d$	<u>22.4</u>
Total	40.6		65.7

a. Adjustment for change in number of male deaths.

$$\frac{1973 \text{ deaths, male}}{1963 \text{ deaths, male}} = \frac{1.10 \text{ million}}{1.03 \text{ million}} = 1.07$$

1973 data source: Monthly Vital Statistics Report, 1974, Table 9,
p. 16 (hereafter, Vital Statistics)

1963 data source: Rice (1966), p. 17

b. Adjustments for change in male mean earnings and supplements to wages.

1.52 = 1.36 x 1.12 per notes b and c for morbidity.

c. Adjustment for change in number of female deaths.

$$\frac{1973 \text{ deaths, female}}{1963 \text{ deaths, female}} = \frac{0.88 \text{ million}}{0.79 \text{ million}} = 1.11$$

1973 data source: Vital Statistics, Table 9.

1963 data source: Rice (1966), p. 17

d. Adjustment for change in female mean earnings.

1.43 was derived as explained by note e for morbidity.

In addition to the Costs of Illness by Rice, the damage estimates drew upon the CHES studies and estimates of the costs associated with respiratory illness. The 1970 estimate from Waddell (1974) was adjusted for the growth in urban population and the increase in the medical care price index as shown below.

$$\begin{aligned} 1973 \text{ damages} &= 1970 \text{ damages} \times \text{adjustment factors} \\ &= \$2.0 \text{ billion} \times 1.046^a \times 1.14^b \end{aligned}$$

a. Adjustment for growth in urban population.

1.046 = $(1.015)^3$ corresponding to three years at the average annual growth rate of 1.5 percent for all SMSA's between 1960 and 1970.

data source: SA74, Table No. 16.

b. Adjustment for change in medical care prices.

$$\frac{\text{medical care price index, 1973}}{\text{medical care price index, 1970}} = \frac{137.7}{120.6} = 1.14$$

data source: SA74, Table No. 98.

2. Calculation of Aesthetic Damages of Air Pollution

The estimates for damage to aesthetic values due to air pollution were computed by adjusting 1970 national estimates for losses in residential property values to account for increases in the housing stock and inflation between 1970 and 1973. The 1970 estimate was developed in Waddell (1974) and was adjusted in that study to avoid duplication with estimates of related benefits or ornamental vegetation and in materials.

$$\begin{aligned} 1973 \text{ Benefits} &= 1970 \text{ Benefits} \times 1.36^{aj} \times 1.14^{bj} \\ &= \$5.8 \text{ billion} \times 1.36 \times 1.14 \\ &= \$8.9 \text{ billion} \end{aligned}$$

a. Adjustment for 3 years' growth in housing stock at 1960's growth rate.

$$\begin{aligned} \frac{\text{Housing Units 1973}}{\text{Housing Units 1970}} &= \frac{3}{10} \cdot \frac{\text{Housing Units, 1970}}{\text{Housing Units, 1960}} \\ &= \frac{3}{10} \cdot \frac{46,496}{38,633} = 0.36 \end{aligned}$$

data source: SA74, Table 1195.

b. Adjustment for GNP deflator.

$$\frac{\text{GNP Deflator, 1973}}{\text{GNP Deflator, 1970}} = \frac{154.31}{135.24} = 1.14$$

data source: Survey of Current Business, July 1974 and July, 1971.

3. Calculation of Air Pollutant Damages to Vegetation

The damages by air pollutants to vegetation were calculated in terms of four components:

- Damage by oxidants to crops
- Damage by oxidants to environmental plants
- Damage by SO₂ and acid rain to crops
- Damage by fluorides to crops

The first amount was derived by the procedure shown below, which reflects new oxidant level measurements in rural areas and results of yield-loss measurements. The other three costs were obtained by doubling the 1964 estimates by Benedict et al. (1971), to account for the approximate

increase in crop prices between 1964 and 1973.

The 1973 data for rural oxidant levels obtained from the EPA National Aerometric Data Bank indicate that the 95th percentile of the oxidant measurements coincides with the national air quality standard of 0.08 ppm. Assuming a normal distribution for these measurements, this suggests that 20-25 percent of the measurements fall between 0.05 and 0.08 ppm. Controlled experiments, including those listed in Table Table II-6, point to an average yield loss of 15 percent and a range of 5-25 percent for similar oxidant levels.

The oxidant level measurements quoted above were taken in areas within 100 miles of major urban centers, and there is reason to believe that they are substantially lower in other areas of the U. S., such as the West North Central, the West South Central, and the Mountain regions. The lower humidity in this region is an additional factor in expecting lower yield losses.

The \$2.8 billion best estimate of damage to crops by oxidants was obtained by multiplying the 15 percent average expected yield loss by \$18.7 billion, which is the 1973 value of crops raised in areas with high expected oxidant levels. The low value of \$0.9 billion was derived by selecting the 5 percent figure for yield loss, while the high value of \$9.5 billion was arrived at by assuming a 25 percent yield loss and high oxidant levels throughout the U.S.

4. Calculation of Air Pollutant Damages to Materials

Estimates of damages to materials by air pollutants were obtained from the 1970 values of Waddell (1974) by applying an inflation factor of 1.14. The value for paint damage was reduced to eliminate overlap with property values. No adjustment was made for changes in stocks of exposed materials.

Table II-6. Studies Comparing Vegetation Yields with Seasonal Ozone Levels

Crop	Yield Loss	Percent of Hours Above		Location	Year	Reference
		0.05ppm	0.08ppm			
Midget Corn	(no. set and fully mature kernels)	n.a.	n.a.	Riverside, Ca.	1974	Thompson & Kats (1975)
Monarch Advance	-45%					
Bonanza	(no. second ears)					
	-75%					
	(bushels/acre)					
Soybeans	-37%	25%	3.3%	Easton, Md.	1973	Howell (1973-1974)
York						
Dare						
Cutler						
Clark						
York	-17%	14%	2.5%		1974	
Dare						
Cutler						
Clark						
Cotton	(weight of lint and seed)			San Joaquin Valley, Ca.		Brewer & Ferry (1974)
Acala SJ-1	-19%	n.a.	17.7%	Parlier	1972	
	-20%	n.a.	n.a.	Hanford		
	-7%	n.a.	9.3%	Five Points		
Acala SJ-1	-31%	n.a.	16.1%(est.)	Parlier	1973	
	-18%	n.a.	n.a.	Hanford		
	-5%	n.a.	n.a.	Five Points		
	-25%	n.a.	n.a.	Cotton Center		
Potatoes	(weight)			Beltsville, Md.	1969	Heggestad (1973)
Susceptible	-49%	9%	5%			
Intermediate	-26%	9%	5%			
	+ 5%	9%	5%			
Susceptible	-34%	15%	8%		1970	
Intermediate	- 2%	15%	8%			
Resistant	- 1%	15%	8%			
Susceptible	-43%	11%	6%		1971	
Resistant	-21%	11%	6%			
Tobacco (Bel-3)	18%	10.8%	n.a.	Georgia	1971	Walker & Barlow (1974)

REFERENCES

- Anderson, Einar, et al., "Effect of Low-Level Carbon Monoxide Exposure on Onset and Duration of Angina Pectoris. A Study in Ten Patients With Ischemic Heart Disease," Ann. Internal Med., 79(1):46-50, July 1973.
- Anderson, R. J. and T. D. Crocker, "Air Pollution and Housing: Some Findings," Purdue University, 1970.
- Aronow, W. S. and M. W. Isbell, "Carbon Monoxide Effect on Exercise-Induced Angina Pectoris," Ann. Intern. Med., 79:392-395, 1973.
- Bates, D. and M. Hazucha, "The short term effects of Ozone on the Human Lung," In: Proc. Conf. on Health Effects of Air Pollutants, U. S. Government Printing Office, 1973.
- Beard, R. R. and G. A. Wertheim, "Behavioral Impairment Associated with Small Doses of Carbon Monoxide," Amer. J. Public Health, 57:2012-2022, 1967.
- Beloin, Norman J. and Fred H. Haynie, "Soiling of Building Materials," Environmental Protection Agency, January 1973.
- Benedict, H. M., et al., "Assessment of Economic Impact of Air Pollution on Vegetation in the United States - 1969 and 1971," Stanford Research Institute, July 1973.
- Booz, Allen & Hamilton Inc., "Study to Determine Residential Soiling Costs of Particulate Air Pollution," U. S. Department of Health, Education and Welfare, 1970.
- Botkin, D. B., et al., "Ozone Suppression of White Pine Net Photosynthesis," J. Air Pollution Control Assoc., 21(12):778-780, December 1971.
- Brewer, W. J. and G. Ferry "Effects of Air Pollution in the San Joaquin Valley," California Agriculture, June 1974.
- Buechley, R. W., et al., "SO₂ Levels and Perturbations in Mortality," Arch. Environ. Health, 27:134-137, September 1973.
- California Air Resources Board, Human Health Damages from Mobile Sources Air Pollution, U. S. Environmental Protection Agency, Washington Environmental Research Center, work in progress.
- Costonis, A. C. and W. A. Sinclair, "Ozone Injury to Pinus Strobus," J. Air Pollution Control Assoc., 19(11):867-871, November 1969.
- Crocker, T. D., "Urban Air Pollution Damage Functions: Theory and Measurement," Environmental Protection Agency, 1971.
- Davis, Charles R., "Sulfur Dioxide Fumigation of Soybeans: Effect on Yield," J. Air Pollution Control Assoc., 22:778-780, December 1972.
- Environmental Protection Agency, "Health Consequences of Sulfur Oxides: A Report from CHESS," May 1974.

Finklea, et al., "Health Effects of Increasing Sulfur Oxides Emissions," Draft Report, U. S. Environmental Protection Agency, March 1975.

Gardner, O. E., Environmental Influences on Living Alveolar Macrophages, University of Cincinnati, 1971.

Gillette, Donald G., "Sulfur Dioxide Standards and Materials Damage," Environmental Protection Agency, 1974.

Goldsmith, J. G. "Effects of Air Pollution on Human Health," In: Air Pollution, Stern, A. C. (ed.) 2nd ed., Vol. 1, New York, Academic Press, 1968.

Goldsmith, J. R. and J. A. Nadel, "Experimental Exposure of Human Subjects to Ozone," J. Air Pollution Control Assoc., 19(5): 329-330, May 1969.

Haynie, Fred H., "The Economics of Clean Air in Perspective," Materials Performance, 13(4): 33-38, April 1974.

Haynie, F. H. and J. B. Upham, "Effects of Atmospheric Sulfur Dioxide on the Corrosion of Zinc," Materials Protection and Performance, 9(8): 35-40, 1970.

Hazucha, M., Effects of Ozone and Sulfur Dioxide on Pulmonary Function in Man, McGill University, 1973.

Heck, W. W. and C. S. Brandt, "Impact of Air Pollutants on Vegetation: Crops, Forests, Native," In: Air Pollution, 1, Stern, A. C. and B. J. Steigerwald (eds.), Academic Press, 1974.

Heck, W. W., et al., "Ozone: Non-Linear Relation of Dose and Injury in Plants," Science, 151(3710): 577-578, 4 February 1966.

Heggestad, H. E., "Photochemical Air Pollution Injury to Potatoes in the Atlantic Coastal States," American Potato Journal, 50, 1973.

Hexter, A. C. and J. R. Goldsmith, "Carbon Monoxide: Association of Community Air Pollution with Mortality," Science, 172: 265-266, April 1971.

Hill, C. A., et al., "Sensitivity of Native Desert Vegetation to SO₂ and to SO₂ and NO₂ Combined," J. Air Pollution Control Assoc., 24(2): 153-157, February 1974.

Horvath, S. M. et al., "Carbon Monoxide and Human Vigilance. A Deleterious Effect of Present Urban Concentrations," Arch. Environ. Health, 23: 343-347, 1971.

Howell, Robert, Unpublished study on soybean yields and ambient ozone exposure, U. S. Department of Agriculture, College Park, Maryland, 1973-1974.

Jaksch, J. A. and H. H. Stoevener, Outpatient Medical Costs Related to Air Pollution in the Portland, Oregon Area, U. S. Environmental Protection Agency, 1974.

Jacobson, J. S. and A. Clyde Hill, Editors, Recognition of Air Pollution Injury to Vegetation, Air Pollution Control Association, Pittsburgh, Pa., 1970.

Lave, L. B. and E. P. Seskin, "An Analysis of the Association Between U. S. Mortality and Air Pollution," J. Am. Stat. Assoc., 68(342):284-290, June 1973.

McCune, D. C., "Fluoride Criteria for Vegetation Reflect the Diversity of the Plant Kingdom," Environmental Science and Technology, 3(8):727-735, August 1969.

Michelson, I. and B. Tourin, "Report on Study of Validity of Extension of Economic Effects of Air Pollution Damage from Upper Ohio River Valley to Washington, D. C. Area," Environmental Health and Safety Research Association, August 1967.

Miller, P. L., "Oxidant-Induced Community Change in a Mixed Conifer Forest," In: Air Pollution Damage to Vegetation by J. A. Naegle, American Chemical Society, Washington, D.C., 1973.

National Academy, E. Sciences, National Academy of Engineering, Air Quality and Automobile Emission Control, U. S. Government Printing Office, 1974.

Nelson, J. P., "Effects of Mobile-Source Air and Noise Pollution on Residential Property Values," U. S. Department of Transportation, 1975.

Neuberger, J. S. and E. P. Radford, "Review of Human Health Criteria for Ambient Air Quality Standards in Maryland," Johns Hopkins University, August 1974.

North Atlantic Treaty Organization, Air Quality Criteria for Particulate Matter, November 1971.

North Atlantic Treaty Organization, Air Quality Criteria for Sulfur Oxides, November 1971.

North Atlantic Treaty Organization, Air Quality Criteria for Photochemical Oxidants and Related Hydrocarbons, February 1974.

North Atlantic Treaty Organization, Air Quality Criteria for Nitrogen Oxides, June 1974.

North Atlantic Treaty Organization, Air Quality Criteria for Carbon Monoxide, 1972.

Pearlman, M. E., et al., "Chronic Oxidant Exposure and Epidemic Influenza," Environmental Research, 4:129-140, April 1971.

Peckham, B. W., "Air Pollution and Residential Property Values in Philadelphia," U. S. Department of Health, Education, and Welfare, 1970.

Randall, Allan, et al., "Benefits of Abating Aesthetic Environmental Damage," New Mexico State University, May 1974.

Ridker, R. G., Economic Costs of Air Pollution, Frederick A. Praeger, New York, 1967.

Ridker, R. G. and J. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," Review of Economics and Statistics, 49:246-257, 1967.

Salmon, R. L., "Systems Analysis of the Effects of Air Pollution on Materials," U. S. Department of Health, Education and Welfare, 1970.

Schloettlin, C. E. and E. Landau, "Air Pollution and Asthmatic Attacks in the Los Angeles Area," Public Health Reports 76:545-548, 1961.

Shy, C., et al., "The Chattanooga School Study: Effects of Community Exposure to Nitrogen Dioxide. Methods, Description of Pollutant Exposure, and Results of Ventilatory Function Testing," J. Air Pollution Control Assoc., 20(8):539-545, August 1970.

Shy, C., et al., "The Chattanooga School Study: Effects of Community Exposure to Nitrogen Dioxide. II. Incidence of Acute Respiratory Illness," J. Air Pollution Control Assoc., 20(9):582-588, September 1970.

Spore, R. L., Property Value Differentials as a Measure of the Economic Costs of Air Pollution, Pennsylvania State University, 1972.

Sprey, P. and I. Takacs, Enviro Control, Inc., Study of Trends in National Air Pollution and Related Effects, U. S. Environmental Protection Agency, December 1974.

Temple, Patrick J., "Dose Response of Urban Trees to Sulfur Dioxide," J. Air Pollution Control Assoc., 22(4):271-274, April 1972.

Thompson, C. R., et al., "Effects of Ambient Levels of Ozone on Navel Oranges," Environmental Science and Technology, 6:1014-1016, November 1972.

U. S. Environmental Protection Agency, "Health Consequences of Sulfur Oxides: A Report from CHESS, 1970-1971," GPO, May 1974.

Upham, J. B., et al., "Fading of Selected Drapery Fabrics by Air Pollutants," Environmental Protection Agency, 1974.

Upham, J. B., J. Air Pollution Control Assoc., 15:265, 1965.

Waddell, T. E., The Economic Damages of Air Pollution, U. S. Environmental Protection Agency, May 1974.

Walker, J. T. and J. C. Barlow, "Response of Indicator Plants to Ozone Levels in Georgia," Phytopathology, 74(8), August, 1974.

Yocom, John E. and Roy O. McCaldin, "Effects of Air Pollution on Materials and the Economy," In: Air Pollution, Stern, A. C. (ed.) 2nd ed., Vol. 1, New York, Academic Press, 1968.

Zelac, R. E., et al., "Ozone as a Mutagen," Environ. Res., 4:262-282, 1971.

Zerbe, R. O., "The Economics of Air Pollution: A Cost-Benefit Approach," Ontario Department of Public Health, 1969.

III. DAMAGES OF WATER POLLUTION

III. DAMAGES OF WATER POLLUTION

This chapter presents estimates of national damages of water pollution for 1973. The areas covered are damage to outdoor recreation, aesthetics and ecological damages, health damages, and production damages.

A. OVERVIEW

The national estimates are introduced here with a summary of the results and a characterization of the procedures followed.

1. Summary of Results

The estimates of national damages associated with water pollution in 1973 are summarized in Table III-1. For each of four damage categories, the table presents a "best" estimate of \$10.1 billion, as well as the low and high limits, which reflect the substantial uncertainty of the best estimate. Loss in property values associated with water pollution is not included here, because it was determined that this would involve double counting of damages already considered under other categories.

Table III-1. Estimated National Damages of Water Pollution for 1973
(\$ billion)

Damage Category	Best Estimate	Range	
		Low	High
Outdoor Recreation	6.3	2.5	12.6
Aesthetic and Ecological	1.5	0.6	2.8
Health	0.6	0.3	1.0
Production (including municipal, industrial, agricultural supplies; commercial fisheries and materials damage)	1.7	1.1	2.3
Total	10.1	4.5	18.7

Since the largest damages occur in the value of recreational uses and in values of water quality that are experienced by non-users, here estimated in the aesthetic, and ecological category, the total estimates strongly reflect the uncertainties inherent in the currently available data and techniques for estimating monetary measures of these values of clean water. The estimation of recreation damages depends upon understanding the behavior of recreationists when confronted with a complex set of choices concerning types of recreation, travel, sites, and the quality of the recreational experience. In determining aesthetic and ecological damages, it is necessary to consider the value which individuals place on viewing or preserving waterways of high quality, even though they do not intend to use them directly.

Despite the difficulties met in developing national damage estimates for water pollution, the \$10.1 billion estimate represents a useful indication that the damages are substantial. Future refinements in the data and techniques used for estimation should lead to a better understanding of the sources of damage, as well as more precise estimates for damages.

2. Procedures

A broad spectrum of studies have been reviewed to obtain information on water pollution control damages. Table III-2 reports

Table III-2. Availability and Reliability of Information on Water Pollution Damages

Pollutant	Outdoor Recreation	Aesthetic and Ecological	Health	Production Losses
Acidity	SF	U	U	SP
BOD	IF	SP	U	IF
Coliform Bacteria	SF	U	SP	SP
Floating Solids	IF	U	U	SP
Hardness	U	U	U	IP
Nutrients	SP	U	U	SP
Odor	U	U	U	U
Oil	SP	SP	U	SP
Pesticides	U	U	U	U
Sediment	IF	IF	U	IF
Temperature	IF	SP	U	SP
TDS and Salinity	U	U	U	IF
TSS and Turbidity	SF	U	U	SP
Toxic Metals	SP	U	U	SP
General Pollution	AF	SP	SP	IF

Availability: A - ample
I - insufficient
S - scarce
U - unavailable

Reliability: E - excellent
G - good
F - fair
P - poor

on the availability and reliability of the information contained in these studies.

Two studies in particular played an important role in the review because they had previously surveyed damage and benefit estimates in the field of water quality and had attempted to produce national estimates. The earlier of the two was written by S. G. Unger, et al. (1974). The more recent study by F. H. Abel, D. D. Tihansky and R. G. Walsh (1975) was being completed at the time the present effort began and was made available in pre-publication draft.

For each category, the studies and estimates available in the literature were reviewed. The best measure of damages was selected and updated for changes in prices, economic activity, population, and other key variables. Details of these calculations are provided in the appendix to this chapter.

B. DAMAGES TO OUTDOOR RECREATION

Outdoor recreation has become the largest component of national damages associated with water pollution. This is due both to the rapid growth of outdoor recreation and to its strong dependence on water quality.

1. Survey of Source Studies

The most popular outdoor recreational activities are swimming, boating, and fishing. All three are strongly affected by quality of the water. Swimming is affected most by fecal coliform and general appearance, whereas the fish population suffers from excessive levels of BOD, salinity, toxic substances, and temperature.

An excellent survey of nearly 50 outdoor recreation damage studies is provided by Jordening (1974). The survey presents tables containing over 30 water characteristics or constituents detrimental to water-based recreational activity, as well as reported damages and established critical levels of specific pollutant.

Seven major source studies were employed in the present calculation of damages. Their respective subject areas are include change in water quality, recreationist reaction to changes in water quality, value of recreation experience, and number of recreation days.

The Council on Environmental Quality (1972) showed that approximately 29 percent of all U.S. stream and shoreline miles were polluted in 1971. This estimate is based on EPA's prevalence-duration-intensity index (PDI index), which allows any water body to be described in terms of the prevalence, duration, and intensity of its water pollution, corrected for natural background pollutant levels. The index is based on how much water quality deviates from Federal-State water quality standards, which vary from place to place, depending on locally established designations as to what the water should be used for (drinking, swimming, industrial waste discharge, etc.). The index covers all U.S. surface waters.

A Wisconsin study by Ditton and Goodale (1972) provides an estimate of:

- The proportion of existing recreation users who would substitute lower priced recreational sites developed by water improvement programs
- The proportion who would experience higher valued recreational activity at these sites
- The increased recreational activity resulting from the lower prices.

The question asked was hypothetical, and what users say they would do and what they actually do when water quality changes are not always the same, though surely related. Users of Green Bay were asked: "What would you do if water conditions deteriorated at the place you do most of your boating, fishing, and swimming?" The study found that not all current users would shift to alternative waterways. Some would discontinue these water-based recreational sports entirely. It was assumed that the same proportion of users who said they would discontinue would start up again when water quality becomes improved. A small proportion reported that they would stay in the same location and participate less, although how much less was not reported. It was assumed that these users would get more pleasure out of the activities after the polluted waterway becomes improved.

Ericson (1975) estimated the willingness to pay for an improvement in the quality of water. At Rocky Mountain National Park in August 1973, 144 tourists were interviewed concerning their willingness to pay for six levels (six color photographs) of water quality on a visual scale of worst conceivable to best. Individuals were willing to pay an average of \$5.75 per day of water-based recreation to avoid the worst polluted water, although the value varied by the income level of the individuals.

The U.S. Fish and Wildlife Service conducts surveys of hunting and fishing at intervals of five years. The 1970 survey was conducted in two parts. In the first part the number of per-

sons 9 years old or older who participated in outdoor recreation were identified. The second part covered in detail the activities of those people who participated substantially in hunting and fishing. This part maintains comparability with the previous surveys and provides the major portion of the information presented in the 1970 survey.

Another source of national recreational patterns is the National Recreation Survey (NRS) which was conducted during September 1972 by the Bureau of Outdoor Recreation to obtain data on the national recreation patterns. This data was then used in an analysis of the present and future demands for various outdoor recreational activities. The survey consisted of personal interviews with members of 4,029 randomly selected households distributed throughout the contiguous United States.

In an outdoor recreation study conducted by Owens (1970), 776 families provided data on participation in 1963. This sample represented a cross section of the urban and rural population of Southern Ohio and nearby areas of West Virginia and Kentucky. Recreationists traveled farther for longer term experiences such as camping than for shorter term activities such as swimming. The speed of travel for recreation was closely associated with distance. Highest average speeds were for the longer trips.

Burt and Brewer (1971) estimated the marginal transfer costs of recreational travel at costs per vehicle mile of 14.2 cents. Their survey of recreation activity at Missouri reservoirs estimated direct travel and on-site costs, excluding investment costs.

Unger, et al. (1974) presents two approximations of the damages to outdoor recreation from water pollution. In this report, two regional studies (Reiling et al., 1973 and Nemerow and Faro, 1970) were synthesized to extrapolate national damages through demand analysis. Total damages were computed as a product of damages per acre, the percent of polluted water, water surface area, and a constant factor to compensate for substitutions in the water-based recreations.

The expenditure method of determining the value of recreation which equates benefits and expenditures, though of questionable validity, provides an alternative method of estimating outdoor recreation benefits. U.S. Bureau of Outdoor Recreation (1967 and 1972) and U.S. Fish and Wildlife Service (1972) studies were the primary sources for this estimate.

2. Damage Estimates

The 1973 damage estimates for outdoor recreation are presented in Table III-3. These estimates are based on the assumption that the 29 percent of U.S. stream and shoreline miles designated as polluted in 1971 would be restored if standards were met. Thus the damages of not controlling water pollution would be a decrease in waterways available for recreation of approximately 41 percent. Federal-state water quality standards, the extent of natural pollution, and the prevalence-duration-intensity (PDI) index, a measure of the severity of water pollution, were used to adjust the number of stream miles, yielding a more precise measure of the potential impact of water pollution on recreation.

The damages from a decrease in water quality arise through three effects: (1) increased costs, particularly travel costs because of shifts to less polluted waterways located farther from major population centers; (2) decreased participation in water-based recreation; and (3) decreased value of recreational experiences because of lower water quality.

The estimation of the damages from increases in cost focuses primarily on the value of travel time and the expenses of travel. The increases in cost are incurred by past users of polluted recreation sites who have substituted cleaner waterways further from home. A recent study by Ericson (1975) shows that a 20 percent change in water pollution can be expected to result in a 20 to 24 percent change in travel to engage in water-based recreation. Using statistics on travel mileage for various types of recreation and data on average speeds, vehicle costs and wages, the damages

Table III-3. Potential Annual Economic Damages to Recreational Users from Water Pollution (in millions of dollars)

Recreation Activity	Recreation Days, 1973 (million days)	Increase in the Price of Existing Recreation Activity		Decrease in Recreation Activity Resulting from Higher Prices		Shift to a Lower Value Recreation Experience		Total	
		Range	Best	Range	Best	Range	Best	Range	Best
Fishing	776	781-2,240	1,510	178-512	345	236-2,360	906	1,200- 5,110	2,760
Boating	434	360-1,020	686	51-143	96	238-2,380	913	649- 3,540	1,700
Swimming (nonpool)	1,162	312-1,110	710	53-188	120	1,239-2,390	915	604- 3,690	1,750
Waterfowl hunting	27	32-88	60	7-20	14	15-148	32	54-256	106
TOTAL	2,400	1,490-4,460	2,970	289-863	576	728-7,280	2,770	2,510-12,600	6,320

were estimated for the 41 percent change in travel costs associated with the 41 percent change in waterways suitable for recreation. Estimates of the percent of recreationists who would shift sites were drawn from a study of Ditton and Goodale (1972) which focused on water-based recreation in Green Bay, Wisconsin.

In addition to the increased costs to recreationists, an increase in the cost of recreation results in a decrease in participation in water-based recreation. The damage of this changed participation was estimated using data developed by Ditton and Goodale (1972). These estimates show that the cost increases from a one percent increase in pollution would result in a 39 percent decrease in total days spent fishing, boating and swimming.

Water pollution also decreases the value of recreational experiences. The study by Ditton and Goodale (1972) also estimated that 21 percent of existing users would experience higher value recreation if pollution were reduced by one percent. The extent of increased value was estimated using Ericson's data on willingness-to-pay for avoiding polluted water. This estimate of \$5.75 per recreation day was developed for tourists in Colorado but was used in the absence of data for other regions.

The recreation damage estimates for each recreation activity are based on recreation days of persons 9 years and older, adjusted for increases in the number of recreation days from 1970 to 1973 because of population growth. Economic factors included in the calculations include wage rates used to establish the value of travel time, vehicle operating costs, and other travel costs, such as food and lodging. However, the 1973 damage estimates have not been adjusted to reflect any changes in water quality since 1971.

C. AESTHETIC AND ECOLOGICAL DAMAGES

Aesthetic and ecological values refer to the positive value which non-users place upon water quality. Users of water in such activities as recreation and, to some extent, production suffer damages because the quality of their experience has been degraded by the presence of pollutants. In this report, such effects and the benefits of reducing them are discussed in the relevant categories of use. Non-users, however, also suffer damages which they would be willing to pay to avoid even though they do not intend to make direct use of the waters involved. These aesthetic and ecological values result from knowledge that clean and natural waterways exist and will be preserved and protected from risk of ecological loss. A part of such willingness-to-pay is the vicarious satisfaction derived from knowledge that the preserved waterway will be used and enjoyed by others, even members of future generations to whom the natural environment is bequeathed.

1. Survey of Source Studies

Damages to non-users result from pollutants that have the greatest impact on the readily sensible aspects of water quality. These include floating debris and oil, clarity, color, and odor. Reduced ability to support wildlife would certainly be considered damaging from the perspective of non-users placing high value on the ecological aspects of water quality.

The primary source study used in estimating the national aesthetic and ecological damages was a study performed in British Columbia (Meyer, 1974). This study focused on a major waterway in Canada, the Fraser River, surveying residents' willingness-to-pay for fishing and preservation of the salmon population. Households were sent a carefully developed questionnaire which placed questions concerning the value of the salmon resource in the context of public service purchases made by the local municipal governments. Respondents were asked to indicate the value they would place on preservation of the river's resources even though they did not expect to use them.

Horvath (1973) estimated the daily value of aesthetic benefits from fish observation and enjoyment to Southeastern U.S. residents at \$143 per household (assuming 2.5 persons per household). The study reported that non-fishermen were assigned the lower values and fishermen the higher. The Southeast Wildlife study did not ask non-users to estimate option value attached to the likelihood that they will be able to fish in the future. However, non-fishermen estimated the daily benefit they would have assigned to fishing at one-third less than the fishermen estimate.

2. Damage Estimates

Although few direct measures of aesthetic and ecological damages are currently available, it is important to provide at least a partial estimate of such benefits because they represent a strong motive for support of water pollution control programs.

The aesthetic and ecological damages from water pollution are estimated to be \$1.5 billion in 1973. This estimate was derived from the study of the Fraser River in British Columbia (Meyer, 1974) which showed that an additional 54 percent or \$223 per household should be added to the value assigned to the river by fishermen to reflect the aesthetic and ecological values of households who did not intend to use the river directly. A similar study in the southeastern United States showed that aesthetic values ranged from 50 to 150 percent of the value of fishing. The estimate of \$1.5 billion reflects the number of households and the value of fishing in the U.S. in 1973. It should be noted that this estimate provides only a rough indication of the aesthetic and ecological damages of water pollution because of the indirectness of the assumed relationships between aesthetic and fishing values in the Fraser watershed and the overall relationship between aesthetic and fishing values in the United States.

D. DAMAGES TO HEALTH

Adverse impacts of water pollution on health provided the earliest impetus for water pollution control. However, because of the high level of treatment provided for drinking water supplies, health damages represent a relatively minor component of the total picture.

1. Survey of Source Studies

Bacteria and viruses are the primary pollutants threatening human health, although recent attention has also focused on carcinogens. Among the diseases that have been investigated are gastroenteritis (including nausea, stomach cramps and diarrhea), infectious hepatitis, meningitis, congenital heart anomalies, and acute myocarditis and pericarditis. The existing literature, however, does not provide sufficient information on the role of a number of pollutants in the etiology of various diseases.

Unger, et al. (1973) present a graphic display of health impact, effect transmissions, and pollutant relationships. The study consisted of a survey and assessment of the state-of-the-art of economic analyses dealing with water pollution control benefits and costs.

Nearly all health damage studies rely on an estimate of reported outbreaks of waterborne illnesses, by Craun and McCabe (1971). During 1961-1970, 128 known outbreaks of disease or poisoning were attributed to drinking water, with 46,369 illnesses and 20 deaths reviewed. Data sources for this study included state health departments, medical and engineering literature, newspaper clippings, and polls of state sanitary engineers and epidemiologists. The study reported that on the average, one waterborne outbreak that is known occurred per month with over 100 persons becoming ill.

2. Damage Estimates

The available studies provide a basis for estimating that \$644 million of damages could have been avoided in 1973 through reduction

in bacterial and viral pollutants. No estimate has been made of the damage from cancer. The estimates are based on data concerning the number of acute clinical cases related to waterborne bacteria and viruses. The economic estimates of the costs of the resulting illnesses include the direct costs of treatment plus the indirect costs of forgone compensation.

The present estimate of \$644 million for damages caused by bacterial and viral pollutants is based on the number of cases of illnesses and unit value data contained in studies by Liu (1970), Lackner (1973), and Sokoloski (1973). Liu (1970) reported annual health damages of \$373 million for 1970. The crude estimate was attributed to the effects of enteric viruses on acute clinical illnesses, and infectious hepatitis cases represented 60 percent of the estimate. An annual health damage estimate of \$356 million was developed by Lackner (1973) on the basis of the incidence of gastroenteritis and other communicable diseases. Sokoloski (1973) estimated health damages at \$120 million, on the basis of reported outbreaks of waterborne diseases and a crude estimate for incidents of infectious hepatitis, congenital heart abnormalities, and aseptic meningitis.

E. PRODUCTION DAMAGES

Because clean water is an important factor in the production of many goods and services, water pollution causes increased production costs and decreased output.

1. Nature of Production Damages

Production uses may be classified as follows:

- Municipal
- Domestic (i.e., household)
- Industrial
- Agricultural
- Commercial fisheries
- Materials damage.

These are taken up in turn below.

Water pollutants cause damages to municipal water supply by increasing both the extent of water treatment required to produce potable water and the costs of maintaining water treatment and supply equipment. The most damaging pollutants are suspended and dissolved solids, bacterial and viral pathogens, metal ions, particularly iron and manganese, inorganic and organic chemicals, and sources of bad odor and taste. The municipal water treatment operations affected by additional pollution are coagulation, filtration, clarification, demineralization and softening, and control of taste and odor. Although disinfection is a major part of municipal water treatment, it appears that this operation would not be substantially reduced by control of man-made effluents.

Although most domestic or household water is drawn from treated surface waters or relatively clean groundwater sources, even these supplies contain damaging pollutants. The effects of these pollutants take the form of damage to pipes, water heaters, fixtures, appliances, fabrics, swimming pools, shrubbery and lawns, which result primarily from dissolved solids and acidity. A major difficulty in the assessment of these damages arises from the need to isolate the

effects of man-made from natural pollution levels, or to put it more precisely, effects which can be altered by pollution control programs from effects which cannot. The damages of interest are those that can be reduced by control programs though it is sometimes difficult to allocate the effects of pollutants to that portion of the overall pollution load which is subject to controls.

The major industrial uses of water are for cooling, boiler feed, and processing. About 25 percent of the 46 billion gallons per day drawn from surface water is treated before use. Boiler feed water must be demineralized and given tertiary treatment before use, but this would be necessary even for natural pollutants. Cooling water, which accounts for more than 67 percent of industrial water intake, is not highly sensitive to pollution, although fouling can cause reduced heat transfer rates and some pollutants reduce equipment life. Although the most troublesome pollutants vary substantially with use, biological organisms, suspended and dissolved solids, and acids are among those most widely treated. The industries most sensitive to pollutants in their water supply are those producing pharmaceuticals, foods and beverages, chemicals, and textiles.

The pollutants most damaging to agriculture are suspended and dissolved solids and micro-organisms. Salinity can reduce crop yields and the range of crop varieties that can be economically raised under irrigation. Sediments can be damaging to some clay soils, but have their greatest impact on irrigation ditches, pumps and nozzels. Bacteria and viruses are also of concern because of the potential for crop contamination and the spread of disease to livestock.

Water pollution has seriously damaged commercial fisheries by reducing the size of the catch, increasing its cost, and lowering its quality. Fecal coliform and other bacteria, reduced oxygen, and toxic metals, such as mercury, have caused the closing of about 20 percent of marine shellfishing areas. National shellfish catches have dropped by more than half since the turn of the century, in part, at least, because of water pollution problems.

The damage to materials caused by water pollution arises in a number of the above categories and has been included wherever appropriate. Materials damage also occurs in the production activities associated with navigation. Damages to navigation arise from the corrosive and abrasive effects of water pollutants on bridges, wharfs, piers, navigation aids, and vessels. Damages also result from sedimentation and from floating debris, including pollution-induced growth of algae and weeds.

2. Survey of Source Studies

The damage estimate for municipal water supply was derived directly from U.S. Census Bureau publications (1970 and 1974) providing treatment costs and water use data. Other researchers, notably Unger et al. (1974), and Bregman and Lenormand (1966), have developed approximations of the damages to municipal water supply using assumptions on the costs of removing man-made pollution. Unit treatment costs resulting from pollution followed Bregman and Lenormand's (1966) arbitrary assumptions of costs per thousand gallons. Bregman and Lenormand estimated that national damages to municipal water supply were between \$118 million and \$1,000 million. Unger et al. revised Bregman and Lenormand's costs per thousand gallon estimates by the consumer price index and estimated 1974 benefits.

National damage estimates for industrial water uses also were reported by Unger et al. (1974). This estimate utilized Bregman and Lenormand's (1966) estimate of pollution related treatment costs per thousand gallons and industrial water use data for the year of the estimate. Unger et al. as previously noted applied the consumer price index to Bregman and Leonard's figures. Additionally, Unger et al. extrapolated their best estimate from Bramer (1960).

Agricultural damage estimates have for the most part followed the methodology presented by Unger et al. (1974). Using variables relating water quality, cost, and land use parameters, Unger et al. calculated the direct salinity impact on agriculture.

The American Society of Agricultural Engineers was the source of the agricultural damage estimate attributed to sediments. A Dow Chemical Company (1972) study developed regional sediment impact estimates on agriculture but the accuracy of extrapolation to the national level is dubious, and has been omitted.

An irrigation water loss estimate was first reported in Holm et al. (1971). They used Timmons' (1960) estimate of acre-feet of water loss and Wollman et al.'s (1962) value of an acre-foot of water.

The commercial fishery damage estimate and range was derived from Tihansky (1973), Bale (1971), Weddig (1973), Council on Environmental Quality (1970), and U.S. Environmental Protection Agency (1975). Inland fishery loss estimates were derived by Weddig (1973). This loss estimate is based on intuition rather than empirical evidence. Tihansky (1973) calculated damages to coastal fisheries by considering price variability in estimating consumer surplus as a damage measure. Bale (1971) and the Council on Environmental Quality (1970) commercial fishery damages estimates were respectively used to compute the upper and lower bounds. Bale's (1974) estimate assumes that only clams and oysters are affected, since they are practically immobile and are harvested primarily in bays and estuaries, which are the most heavily polluted marine areas. CEO's (1970) estimate assumes that all major shellfish -- lobsters, shrimp, and crabs -- are affected by contamination. The U.S. Environmental Protection Agency annually reports fish kills where water pollution is known or suspected to be the cause of death. This report includes information on the fish kill's location by state and source of pollution by economic sector.

Tihansky (1973) was the primary source of the estimate of damages to domestic water use. Damages were translated into economic losses for a typical household on various water supply sources (e.g., surface or groundwater), and then aggregated at the national and individual state levels. The most damaging pollutants are hardness and total dissolved solids, followed by chlorides, sulfates, and

acidity. Damage functions in this study were formulated from actual data observations on household item uses.

The materials damage estimate synthesizes elements of estimates presented in American Society of Agricultural Engineers paper 70-701 and Unger et al. (1974). The ASAE paper contains a very crude estimate of damages attributed to sediment particles on floodplains, irrigation ditches, hydro-turbines, and commercial fishery facilities. Unger et al. (1974) reported Bramer's (1960) estimate of damages from acid corrosion reduction in the Ohio River Basin. In a later work Bramer (1972) specified the damages from acid corrosion which can be attributed to navigation.

3. Damage Estimates

The national damages from water pollution in production activities have been estimated to be \$1.6 billion in 1973. Table III-4 shows the breakdown of these damages by the subcategories discussed above.

Table III-4. Estimated National Production Damages
Attributed to Water Pollution, 1973
(\$ billions)

Damage Category	Best Estimate	Range	
		Low	High
Municipal	0.41	0.34	- 0.47
Industrial	0.30	0.22	- 0.37
Agricultural	0.07	0.05	- 0.08
Commercial Fisheries	0.10	0.02	- 0.14
Domestic	0.35	0.13	- 0.69
Materials Damage	0.42	0.32	- 0.53

The municipal treatment costs that result from water pollution were estimated under the assumption that 39 percent of the total costs are related to pollution caused by man and subject to pollution control. This assumption is supported by a study performed in Illinois by Barker and Kramer (1973). On the average, this means that a cost of 5 cents per thousand gallons of municipal water supply is incurred because of water pollution. The resulting damage estimate for 1973 is \$0.41 billion.

Industrial treatment costs for removal of man-made pollutants from self-supplied (as contrasted with municipally supplied) water were also estimated using data from the Barker and Kramer study. This study found the cost of industrial treatment for man-made pollutants to be about 4 cents per thousand gallons in 1972. For the volumes of water treated in 1973, the damage costs of water pollution are estimated to be \$0.29 billion. In addition, industries must use more blow-down water for cleaning pollutants from boilers and cooling towers. Using an estimate developed for the Santa Ana Watershed by Sonnen (1973), the resulting damages, extrapolated to other major western watersheds and adjusted for man-made salinity, are estimated to be \$1.6 million. Thus the total industrial damages are estimated to be \$0.215 billion in 1973.

The agricultural damages are estimated to be \$0.066 billion in 1973. Agricultural damages result primarily from sediments. Sediment removal costs account for about half of the maintenance costs of drainage ditches and irrigation canals. Estimates of these costs, revised to reflect inflation, show \$66 million in annual benefits in 1973. One other pollutant, salinity, has been considered although its damages are not included in the estimates of damages to agriculture. Water draining from irrigated fields upstream has greater salinity than normal surface water. An estimate of the damages caused by this increased salinity may be made by assuming that 40 percent of total salinity results from man-made sources, an assumption supported by the Westwide Study of water problems in the eleven western states (U.S. Department of the Interior, 1974). In

addition, previous studies of the economic loss in crop yield (Kleinman, et al., 1974) can be revised to reflect the increase in farm value of crops in western states. Using these figures and data on the irrigated acreage and the salinity in each of the major western basins, the resulting estimate of the damages due to salinity is \$0.529 billion in 1973.

However, it is important to note that the achievement of benefits from reductions in such damages depends on the actual operation of agricultural markets. Increased yields and reduced operating costs should lower agricultural prices and increase output. If agricultural markets are under government regulation which prevent price decreases or expansion in production, the reductions in the costs of farm production resulting from reduction in saline pollution may result in increased farm profits without benefit to consumers. The benefit estimate of \$0.654 billion reflects the value of increased production assuming that it could be sold at prices prevailing in 1973. For this reason and because it is not clear whether the net benefits of upstream agriculture are greater than, less than, or equal to the salinity damages to downstream agriculture, this estimate is not included in the total damages.

As pointed out above, damages to commercial fisheries result from decreased catch, increased costs and decreased quality of fish. In marine fisheries, the estimated damages are \$53 million. These estimates considered the impact of decreased catches on the price of fish to consumers using demand functions developed by the National Marine Fisheries Service. Estimates of the value of a 26 percent change in landings of clams, oysters and marine finfish developed using this technique by Tihansky (1973) were revised to reflect increases in the value of fish landings from 1970 to 1973.

Fresh water commercial fisheries also suffer damages from water pollution that can be reduced through pollution control. Weddig (1973) estimated inland fisheries losses to be \$35 million. Adjustments were made to this figure to account for price changes be-

tween 1970 and 1973 giving an estimate of \$49 million. The resulting estimate of total damages to marine and fresh water commercial fisheries is \$102 million.

In the production of household services, the estimated 1973 damages from water pollution are \$346 million. This estimate is based on a series of studies synthesized by Tihansky (1973). Damages were first estimated for each household item giving consideration to both operating and investment costs. Household damages developed by considering the percent of households owning each item were then aggregated to the state and national level. Water quality data was obtained by contacting experts in each state. As the result of regional analyses of mineral sources, it was estimated that about 17 percent of dissolved solids and hardness are due to man's activities. The 1973 estimates reflect adjustments for population growth and inflation since 1970, the date of the original estimates.

Water pollution causes damages to materials used in other production activities in addition to those discussed above. The primary category of such damages is navigation with an estimated \$167 million annual damages in 1973. Damages of \$7 million results from increased maintenance and replacement costs for structures and vessels exposed to polluted water. This estimate was derived by updating estimates for 1958 from Bramer (1972). The remainder of the damages to navigation result from the costs of dredging sediments from inland navigation channels and harbors. The 1973 estimate of \$160 million for this cost was developed by adjusting cost estimates from 1948 (see American Society of Agricultural Engineers paper 70-701) to reflect inflation.

Sedimentation also causes damages to floodplains, to water storage reservoirs, and to vessels and other waterborne equipment. Estimates of these damages have been developed using the same 1948 source study. The 1973 estimate is \$253 million. Thus, the total estimate of materials damage is \$420 million.

F. PROPERTY VALUE DAMAGES

Although property value damages have not been included in the material estimates of damages for reasons discussed below, there has been substantial work estimating such damages that warrants discussion. A national estimate puts property value losses at \$84 million in 1973.

1. Survey of Source Studies

The effects of water pollution on the value of water uses have been shown to be reflected in the value of nearby properties. The water uses whose values most strongly influence property values are those facilitated by ownership of the land, namely recreation, aesthetic enjoyment and ecological enjoyment. Production activities and health are less dependent on locations directly adjacent to water. Damages in these categories are thus less strongly reflected in property values. Residential and recreational properties are similarly more affected by water pollution than commercial and industrial properties, except for those commercial activities directly related to water recreation.

The primary study of water pollution and property values was performed under EPA sponsorship by Dornbusch and Barrager (1973). This included an interview survey of property owners in seven areas where pollution abatement had occurred. The responses indicated that wildlife support capacity is more important to property owners than aesthetics or recreation. The pollutants having strongest damaging effect on fish and wildlife are included in the National Sanitation Foundation's FAWL Index. These are biological oxygen demand, heat, acidity, phenols, turbidity, ammonia, dissolved solids, nitrate and phosphate. The pollutants most strongly affecting aesthetics and recreation as discussed in previous sections include floating debris, oil, odor, clarity, color, and fecal coliform.

The Dornbusch and Barrager study applied multiple-regression analysis to determine the relationship between changes in property values (as determined by sales prices) and water quality (as deter-

mined by sales prices) and water quality (as determined by the EPA Pollution-Duration-Intensity Index). The results from seven case study areas were extrapolated to provide a national estimate by separately considering metropolitan areas, towns and rural areas. The estimated capital value of \$0.6 to \$3.1 billion in 1972 was annualized at 6 percent discount rate giving \$33 to \$175 million per year with a best estimate of \$76 million.

In an earlier study Nemerow and Faro (1969) showed that property along the shore of Onondaga Lake near Syracuse, N.Y. would increase in value by over \$1 million per year if the PDI index were lowered from 5 to 1. David and Lord (1969) found that improvements in water quality on artificial lakes in Wisconsin would increase adjacent property values by 7 percent. In a study of Rocky Mountain National Park, Ericson (1975) found that tourists in Colorado were willing to pay 123 percent more for land adjacent to unpolluted waterways. All of these studies confirm the positive relationship between water quality and property value although the strength of the relationship clearly varies from place to place.

2. Damage Estimates

The Dornbusch and Barrager study analyzed the variation in property value due to location near waterways with improved water quality. National damages were extrapolated from studies of seven areas which showed that values of property within 4,000 feet of waterways increased from 3 to 25 percent as a result of pollution abatement. The resulting estimate of annualized damages, adjusted to reflect increases in property values from 1972 to 1973, is \$84 million.

However, until additional study has been completed, it is probably best to regard this estimate as substantially duplicative of estimates for other damages. While statistics show that recreational use by local population is a small fraction of total use, the Dornbusch and Barrager interviews show that wildlife support and aesthetics together account for 76 percent of the total value.

Since damages in these categories are estimated elsewhere not only for property owners, but for the general population, they should not be included in an additional estimate derived from a property value study. For the remaining 24 percent of the value of water quality, which is associated with recreation, much of the estimated damage is due to recreational properties whose value is also reflected in studies of recreationists willingness-to-pay. Thus, it seems better at this time to regard property value indicators as a confirmation of the damages of pollution but not as a source of additional damages estimates.

REFERENCES

Abel, Fred H., Dennis P. Tihansky, and Richard G. Walsh, National Benefits of Water Pollution Control, U.S. Environmental Protection Agency, 1975.

American Society of Agricultural Engineers, professional paper 70-701.

Bale, H. E., Jr., Report on the Economic Costs of Fishery Contaminants, U.S. Department of Commerce, National Marine Fisheries Service, October 1961.

Barker, Bruce and Paul Kramer, "Water Quality Conditions in Illinois," in Statewide Water Resource Development Plan 1972, Illinois Department of Transportation, Division of Water Resource Management, 1973.

Bramer, Henry C., The Economic Aspects of the Water Pollution Abatement Program in the Ohio River Valley, Ph.D. Dissertation, University of Pittsburgh, 1960.

Bramer, Henry C., "Economically Significant Physicochemical Parameters of Water Quality for Various Uses," Mellon Institute, 1972.

Bregman, J. and S. Lenormand, The Pollution Paradox, Spartan Books, Inc., New York, 1966.

Burt, Oscar R. and Durward Brewer, "Estimation of Net Social Benefits from Outdoor Recreation," Econometrica, September 1971.

Council on Environmental Quality, Environmental Quality - 1972, The Third Annual Report of the Council on Environmental Quality, August 1972.

Council on Environmental Quality, Ocean Dumping: A National Policy, 1970.

Craun, Gunther F., and Leland J. McCabe, "Waterborne-Disease Outbreaks, 1961-1970," U.S. Environmental Protection Agency, Water Supply Division, paper presented at the Annual Meeting of the American Waterworks Association, June 1971.

David, Elizabeth L. and William B. Lord, "Determinants of Property Value on Artificial Lakes," University of Wisconsin, Department of Agricultural Economics, Agricultural Economics, May 1969,

Ditton, Robert and Thomas Goodale, Marine Recreation Uses of Green Bay: A Study of Human Behavior and Attitude Patterns, Technical Report No. 17, University of Wisconsin, Sea Grant Program, December 1972.

Dornbusch, David M. and Stephen M. Barrager, Benefit of Water Pollution Control on Property Values, U.S. Environmental Protection Agency, EPA-600/5-73-005, October 1973

Dow Chemical Company, An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization, February 1972.

Ericson, Raymond K., Valuation of Water Quality in Outdoor Recreation, forthcoming Ph.D. Dissertation, Colorado State University, 1975.

Holm, L. G., L. W. Weldon, and R. D. Blackburn, "Aquatic Weeds," in Man's Impact on Environment, Thomas R. Detwyler (ed.), McGraw-Hill, New York, 1971.

Horvath, Joseph C., "Economic Survey of Southeastern Wildlife and Wildlife-Oriented Recreation," Transactions, the 39th North American Wildlife and Natural Resource Conference, Wildlife Management Institute, Washington, D.C., April 1974.

Jordening, David L., Estimating Water Quality Benefits, U.S. Environmental Protection Agency, EPA-600/5-74-014, August 1974.

Kleinman, Alan P., J. Barney Glad, and Sigurd G. Titnus, Economic Impacts of Changes in Salinity Levels of the Colorado River, U.S. Department of the Interior, Bureau of Reclamation, February 1974.

Lackner, Jack, Safe Drinking Water Act of 1973: Estimated Benefits and Costs, U.S. Environmental Protection Agency, 1973.

Liu, Oscar C., Illnesses Associated With Human Enteric Viruses, U.S. Environmental Protection Agency, Northeast Water Supply Research Laboratory, 1970.

Meyer, Philip A., Recreational and Preservation Values Associated With the Salmon of the Fraser River, Fisheries and Marine Service, Vancouver, B.C., Canada, Information Report Series, No. PAC/N-74-1, 1974.

Nemerow, Nelson L. and Robert C. Faro, Measurement of the Total Dollar Benefit of Water Pollution Control, Syracuse University, January 1969.

Nemerow, Nelson L. and Robert C. Faro, "Total Dollar Benefit of Water Pollution Control," Journal of the Sanitary Engineering Division, 1970.

Owens, Gerald P., Outdoor Recreation: Participation, Characteristics of Users, Distances Traveled, and Expenditures, Ohio Agricultural Research and Development Center, Research Bulletin 1033, April 1970.

Reiling, S. D., K. C. Gibbs, and H. H. Stoevener, Economic Benefits from an Improvement in Water Quality, U.S. Environmental Protection Agency, EPA-R5-73-008, January 1973.

Sokoloski, A., Economic Benefits of an Adequate Supply of Safe Water, U.S. Environmental Protection Agency, 1973.

Sonnen, Michael B., "Quality Related Costs of Regional Water Users," paper presented at the ASCE National Meeting on Water Resources Engineering, 29 January - 2 February 1973.

Tihansky, Dennis P., "An Economic Assessment of Marine Water Pollution Damages," Proceedings of the Third International Conference on Pollution Control in the Marine Industries, 5-7 June 1973.

Tihansky, Dennis P., Economic Damages to Household Items from Water Supply Use, U.S. Environmental Protection Agency, July 1973.

Timmons, F. L., U.S. Department of Agriculture ARS-34-14, 1960.

Unger, Samuel G., M. Jarvin Emerson, and David L. Jordening, State-of-Art Review: Water Pollution Control Benefits and Costs, U.S. Environmental Protection Agency, EPA-600/5-73-008a, October 1973.

Unger, Samuel G., et al., National Estimates of Water Quality Benefits, Development Planning & Research Associates, Inc., November 1974.

U.S. Bureau of the Census, Census of Manufacturers, 7th Subject Report Water Use in Manufacturing, U.S. Government Printing Office, 1970.

U.S. Bureau of the Census, Governmental Finances in 1972-73, Series GS73, No. 5, U.S. Government Printing Office, 1974.

U.S. Bureau of the Census, Statistical Abstract of the United States: 1974, 95th ed., Washington, D.C., 1974.

U.S. Bureau of Outdoor Recreation, The 1970 Survey of Outdoor Recreation Activities - Preliminary Report, U.S. Department of Interior, February 1972.

U.S. Bureau of Outdoor Recreation, The 1965 Survey of Outdoor Recreation Activities, U.S. Department of Interior, 1967.

U.S. Bureau of Outdoor Recreation, Outdoor Recreation - A Legacy for America, U.S. Department of Interior, December 1973.

U.S. Department of Interior, Westwide Study Report on the Critical Water Problems Facing the Eleven Western States, 1974.

U.S. Environmental Protection Agency, Fish Kills Caused by Pollution in 1971 - Twelfth Annual Report, 1972.

U.S. Fish and Wildlife Service, National Survey of Fishing and Hunting 1970, U.S. Department of Interior, 1972.

Weddig, Lee J., National Fish Institute, Inc., Washington, D.C., personal communication, January 1973.

Wollman, Nathaniel, et al., The Value of Water in Alternative Uses With Special Application to Water Use in the San Juan and Rio Grande Basins of New Mexico, University of New Mexico Press, Albuquerque, 1962.

APPENDIX. CALCULATION OF WATER POLLUTION DAMAGES

1. Calculations for Outdoor Recreation Damages from Water Pollution

The estimates of damages to outdoor recreation resulting from water pollution were computed for fishing, boating, swimming (nonpool), and waterfowl hunting. For each activity, damages were computed for each of the following:

- Increase in the price of existing recreation activity
- Decreased recreational activity resulting from higher prices
- Shift to a lower value recreation experience.

Table III-5 summarizes the potential annual economic damages to recreational users from water pollution.

Calculations and Data Sources for Increase in the Price of Existing Recreation Activity

The damage estimates were computed for each of the major activities shown in the following table. Values in columns a through e were determined as described in subsections a through e.

Activity	a 1973 Recreation days (in millions)	x	b Average mileage per recreation day	x	c Proportion of recreationists who will shift their recreation x site	x	d Proportional increase in unpolluted waterways	x	e Transfer cost per person per mile (in dollars)	=	Damages of in- creased price of recreation activity (in \$ millions)
Fishing	776		41.8		0.797		0.414		.141, .073, .209		1509, 781, 2237
Boating	434		43.3		0.634		0.414		.134, .073, .207		686, 360, 1021
Swimming	1,162		10.3		0.863		0.414		.166, .073, .259		710, 312, 1107
Waterfowl hunting	27		49.6		0.797		0.414		.136, .073, .199		60, 32, 88

Table III-5. Potential Annual Economic Damages to Recreational Users from Water Pollution (in millions of dollars)

Recreation Activity	Recreation Days, 1973 (million days)	Increase in the Price of Existing Recreation Activity		Decrease in Recreation Activity Resulting from Higher Prices		Shift to a Lower Value Recreation Experience		Total	
		Range	Best	Range	Best	Range	Best	Range	Best
Fishing	776	781-2,240	1,510	178-512	345	236-2,360	906	1,200-5,110	2,760
Boating	434	360-1,020	686	51-143	96	238-2,380	913	649-3,540	1,700
Swimming (nonpool)	1,162	312-1,110	710	53-188	120	1,239-2,390	915	604-3,690	1,750
Waterfowl hunting	27	32-88	60	7-20	14	15-148	32	54-256	106
TOTAL	2,400	1,490-4,460	2,970	289-863	576	728-7,280	2,770	2,510-12,600	6,320

a.

Activity	1970 Recreation days 9 years and older (in millions)	1970-1973 Population x increase =	1973 Recreation days (in millions)
Fishing	753	1.03	776
Boating	421	1.03	434
Swimming	1,128	1.03	1,162
Waterfowl hunting	26	1.03	27

Fishing and hunting data source is: U.S. Fish and Wildlife Service National Survey of Fishing and Hunting 1970, United States Department of the Interior, Bureau of Sport Fisheries and Wildlife, 1972 (hereafter National Survey of Fishing and Hunting 1970), pp. 4, 32, 11 (12.2% of young sportsmen hunting was attributed to waterfowl hunting).

Boating and swimming data sources are as follows: U.S. Bureau of Outdoor Recreation, The 1970 Survey of Outdoor Recreation Activities - Preliminary Report, U.S. Department of the Interior, February 1972 (hereafter The 1970 Survey of Outdoor Recreation Activities - Preliminary Report), p. 8, Table B (swimming recreation days included pool swimming; from the source cited below, it was calculated that nonpool swimming was 62.5% of total swimming).

Population data source is: U.S. Bureau of the Census, Statistical Abstract of the United States: 1974, 95th ed., Washington, D. C., 1974 (hereafter Statistical Abstract of the United States: 1974), p. 5, Table 2.

b.

Activity	Passenger miles traveled 1970 (in millions)	Recreation days 12 years and older 1970 (in millions) ÷	Average mileage per = recreation day
Fishing	29,483	706	41.8
Waterfowl hunting	1,239	25	49.6
Boating			43.3
Swimming			10.3

Fishing and waterfowl hunting data source is: National Survey of Fishing and Hunting 1970, p. 4, 11.

Boating and swimming data source is: Owens, Gerald P., Outdoor Recreation: Participation, Characteristics of Users, Distances Traveled, and Expenditures, Ohio Agricultural Research and Development Center, Wooster, Ohio, Research Bulletin 1033, April 1970 (hereafter Outdoor Recreation: Participation, Characteristics of Users, Distances Traveled, and Expenditures), p. 11, Table 5. (The mean number of miles traveled as reported in Table 5 was multiplied by the number of miles traveled while fishing reported above and divided by mean miles traveled while fishing as reported in Table 5.)

c. Calculations for the proportion of recreationists who will shift their recreation site are:

Activity	<div> <div> Move to a location on Green Bay (%) </div> <div> + </div> <div> Move to a location not on Green Bay (%) </div> </div> <div> <div> Would not bother me(%) + location but participate less frequent- </div> <div> Stay in same location but + participate less frequent- </div> <div> Move to a location on Green Bay (%) </div> <div> + </div> <div> Move to a location not on Green Bay (%) </div> </div>	= Proportion of recreationists who will shift their recreation site
Fishing	<div> <div> <div>22.4</div> <div>5.5</div> <div>+</div> <div>8.3</div> <div>+</div> <div>31.9</div> <div>22.4</div> <div>+</div> <div>31.9</div> </div> </div>	0.797
Boating	<div> <div> <div>18.4</div> <div>13.5</div> <div>+</div> <div>14.3</div> <div>+</div> <div>30.5</div> <div>18.4</div> <div>+</div> <div>30.6</div> </div> </div>	0.634
Swimming	<div> <div> <div>20.4</div> <div>2.4</div> <div>+</div> <div>7.3</div> <div>+</div> <div>43.7</div> <div>20.4</div> <div>+</div> <div>43.7</div> </div> </div>	0.863
Waterfowl hunting	assumed fishing proportion	

Passenger cost per mile for 1973 was calculated in the following way: passenger cost per mile (\$.087) for 3.2 persons (1966) was multiplied to adjust for 2.26 persons per vehicle (.7) and then multiplied by the GNP implicit price deflator (1.384, 1966-1973) to account for price increases. Vehicle cost per mile was calculated as follows: an estimate of vehicle cost per mile (\$.055, 1966) was multiplied by the GNP implicit price deflator (1.384, 1966-1973) and then another vehicle cost per mile estimate (\$.0867, 1973) was added to the former product and the sum was averaged. The two estimates of regional vehicle cost per mile were then averaged to provide a more reasonable estimate of national vehicle cost per mile. The number of persons per vehicle was calculated as follows: millions of passenger miles traveled while fishing (29,483) was divided by millions of miles traveled while fishing (13,035).

Data sources are as follows: Burt, Oscar R., and Durward Brewer, "Estimation of Net Social Benefits from Outdoor Recreation," Econometrica, September 1971, p. 822.
Statistical Abstract of the United States: 1974, p. 405, Table 658.
 U.S. Federal Highway Administration, Cost of Operating An Automobile, U.S. Department of Transportation, April 1974, p. 1 [cost included maintenance, accessories, parts, tires, gas and oil (excluding taxes), garage, parking, and tolls plus state and federal taxes; these costs were averaged for the three sizes of cars].
National Survey of Fishing and Hunting 1970, pp. 84-5 (number of passenger miles traveled while fishing divided by the number of miles traveled while fishing equals persons per vehicle).

Computations for travel time cost per person per mile are:

Activity	Compensation rate per hour (in dollars) ÷	Travel miles per hour =	Travel time cost per person per mile (in dollars)
Fishing	2.50, 0, 5.00	36.9	.068, 0, .136
Boating	2.50, 0, 5.00	37.7	.066, 0, .135
Swimming	2.50, 0, 5.00	26.9	.093, 0, .186
Waterfowl hunting	2.50, 0, 5.00	39.6	.063, 0, .126

Calculations and data sources for compensation rate per hour are as follows: a \$2.50 compensation rate for all activities was calculated by averaging the compensation rates computed for each activity. For each activity, recreation days in the total civilian labor force were divided by recreation days for the total civilian population; this dividend was then multiplied by a wage rate of \$3.43 for employed persons. Also, the number of recreation days for persons not in the labor force was divided by the recreation days for the total civilian population; this dividend was then multiplied by a wage rate of \$2.13 to account for the value of uncompensated household workers.

Data source is: The 1970 Survey of Outdoor Recreation Activities - Preliminary Report, pp. 18, 24, 36, 54. (The average daily compensation of employed workers was added to the daily value of housework by employed workers with two children; the sum was divided by the hours worked. The compensation wage for persons not in the labor force was calculated by dividing the average daily value of household work for unemployed housewives with two children by the average daily hours worked).

Data sources are as follows: U.S. Department of Commerce, Survey of Current Business, 54(7), July 1974, p. 36.

Walker, Kathryn E., and William H. Gauger, The Dollar Value of Household Work, New York State College of Human Ecology, Information Bulletin 60, 1973, pp. 6-8, Chart and Table 1. (A \$5.00 upper limit for compensation rate was an arbitrary but not unrealistic estimate).

Data sources for travel miles per hour are as follows: Outdoor Recreation: Participation, Characteristics of Users, Distances Traveled, and Expenditures. (Figure for boaters' travel miles per hour was calculated by using miles per hour figures in Table 5 for power boating, canoeing-rowing-sailing, and water skiing, weighted by the recreation days for each in the citation below).
Outdoor Recreation - A Legacy for America, p. 4, Table 1.

Computations and Data Sources for Decreased Recreational Activity Resulting From Higher Prices

The damage estimates were computed for each of the major activities shown in the following table. The values in columns a and b were computed as described in subsections a and b.

Activity	a	b		
	Proportional potential decrease in activity resulting from	1973 Damages of increased price of existing recreation activity x (in \$ millions) x	Factor to account for slope of the demand curve	Damage of decreased recreational activity resulting from higher prices = (in \$ millions)
Fishing	.457	1510, 781, 2240	.5	345, 178, 512
Boating	.281	686, 360, 1020	.5	96, 51, 143
Swimming	.338	710, 312, 1110	.5	120, 53, 188
Waterfowl hunting	.457	60, 32, 88	.5	14, 7, 20

a. Calculations for proportional potential decrease in activity resulting from higher prices are:

Activity	Stop participating entirely (%)				Proportional potential decrease in activity resulting from higher prices
	Would not bother me + (%)	Stay in same location but participate less frequently (%)	Move to a location on + Green Bay (%)	Move to a location not on Green Bay (%)	
Fishing	5.5	8.3	22.4	31.9	0.457
Boating	13.5	14.8	18.4	30.6	0.281
Swimming	2.4	7.8	20.4	43.7	0.338
Waterfowl hunting	assume fishing proportion				

Data source is: Marine Recreation Uses of Green Bay, p. 94, Table V-7.

- b. From section "Computations and Data Sources for Increase in the Price of Existing Recreation Activity."

Computations and Data Sources for Shift to a Lower Value Recreation Activity

The damage estimates were computed for each of the major activities shown in the following table. Values in columns a, b, and c were computed as shown in subsections a, b, and c.

Activity	a Proportion of existing recreationists who experience lower value recreation activity	b 1973 Recreation days x (in millions)	c Value of degraded quality (in dollars) Damage of a shift to a lower value recreation experience = (in \$ millions)
Fishing	.203	776	5.75, 1.50, 15.00 906, 236, 2,363
Boating	.366	434	5.75, 1.50, 15.00 913, 238, 2,383
Swimming	.137	1,162	5.75, 1.50, 15.00 915, 293, 2,383
Waterfowl hunting	.366	27	5.75, 1.50, 15.00 32, 15, 148

- a. Calculations for the proportion of existing recreationists who experience lower value recreation activity are:

Activity	<div> <div> Would not bother me (%) </div> <div> Stay in same location but participate less frequently (%) </div> <div> Would not bother me + Stay in same location but participate less frequently (%) </div> <div> Move to a location on Green Bay (%) </div> <div> Move to a location not on Green Bay (%) </div> </div>	Proportion of existing recreationists who experience lower value recreation activity
Fishing	<div> <div>5.5</div> <div>5.5</div> <div>+</div> <div>8.3</div> <div>+</div> <div>22.4</div> <div>+</div> <div>31.9</div> </div>	0.203
Boating	<div> <div>13.5</div> <div>13.5</div> <div>+</div> <div>14.8</div> <div>+</div> <div>18.4</div> <div>+</div> <div>30.6</div> </div>	0.366
Swimming	<div> <div>2.4</div> <div>2.4</div> <div>+</div> <div>7.3</div> <div>+</div> <div>20.4</div> <div>+</div> <div>43.7</div> </div>	0.137
Waterfowl hunting	assume fishing proportion	

Data source is: Marine Recreation Uses of Green Bay, p. 94, Table V-7.

- b. See section, "Computations and Data Sources for Increase in the Price of Existing Recreation Activity," subsection a.
- c. Data source for the value of degraded quality is: Ericson, Raymond, Valuation of Water Quality in Outdoor Recreation, forthcoming Ph.D. Dissertation, Department of Economics, Colorado State University, Fort Collins, 1975. (Ericson in a personal communication stated that the range is \$1.50 to \$15.00.)

2. Computations for Aesthetic Damage of Water Pollution

The estimates for damages resulting from destruction of the natural state of the environment by water pollution were computed by use of two basic sources:

- Meyer (1974)
- The fishing damage estimate discussed previously.

Meyer (1974) estimated the annual preservation and recreational value associated with the salmon of the Fraser River by residents of the Fraser River Basin. A percentage relationship was derived from Meyer's study. This relationship between fishing and aesthetic damages was assumed to map onto the United States. The derivation of fishing damage estimates appears in part 1, "Calculations for Outdoor Recreation Damages from Water Pollution."

Computations and Data Sources for Estimates of Aesthetic Damages

Proportional relationship between aesthetics and fishing damages	x	Fishing damage estimates from 1. Outdoor Recreation (in \$ millions)	= Aesthetic damages (in \$ millions)
0.54 ^a	x	2760, 1200- 5110 ^b	= 1490, 648, 2760

a.	Total preservation value (in dollars)	Grand total recreation value ÷ (in dollars)	= Proportional relationship
	100, 559, 174	÷ 185, 596, 654	= 0.54

Data source is: Meyer, Philip A., Recreational and Preservation Values Associated With the Salmon of the Fraser River, Fisheries and Marine Service, Vancouver, B. C., Canada, Information Report Series No. PAC/N-74-1, 1974, p. 17, Tables X and XI.

- b. Fishing damage estimates were derived from part 1, "Calculations for Outdoor Recreation Damages from Water Pollution," Table III-5.

3. Computations for Production Damages of Water Pollution

Production damages have been grouped into the following classes:

- Municipal water supply
- Industrial water uses
- Agricultural water uses
- Commercial fisheries
- Domestic water uses
- Materials damage.

The estimates for each damage class and the derivation of these estimates will be discussed in the subsections below:

Computations and Data Sources for Damages to Municipal Water Supply

Proportion of pollution attributed to man	x	Cost of current operation (in \$ millions)	x	Factor to account for treatment versus distribution costs	=	Municipal water supply damages (in \$ millions)
.39^a	x	2120^b	x	0.5^c	=	413^d

- a. Data source for the proportion of pollution attributed to man is: Barker, Bruce, and Paul Kramer, "Water Quality Conditions in Illinois," In Statewide Water Resource Development Plan 1972, Illinois Department of Transportation, Division of Water Resource Management, 1973 (hereafter "Water Quality Conditions in Illinois").
- b. Data source for the cost of current operation of water supply systems is: U. S. Bureau of the Census, Government Finances in 1972-73, Series GS73, No. 5, U. S. Government Printing Office, Washington, D. C., 1974, p. 44, Table 21.

Data source for billions of gallons of treated process water 1968 is: U. S. Bureau of the Census, Census of Manufacturers, 7th Subject Report, Water Use in Manufacturing, U. S. Government Printing Office, 1970, p. 7-69, Table 4 (hereafter Water Use in Manufacturing).

Data source for the factor to account for increase in treated water withdrawals 1968-1973 is: Statistical Abstract of the United States: 1974, p. 175, Table 295.

b. Computations for cost of treatment per thousand gallons 1973 are:

Cost of treatment per thousand gal- lons 1972, 1958 (in dollars)	x	GNP implicit price deflator 1972-1973, 1958-1973	=	Cost of treatment per thousand gallons 1973 (in dollars)
.040, .038	x	1.053, 1.539	=	.042, .058

Data sources for cost of treatment per thousand gallons 1972, 1958 are as follows: "Water Quality Conditions in Illinois." Bramer, Henry C., The Economic Aspects of the Water Pollution Abatement Program in the Ohio River Valley, Ph.D. Dissertation, University of Pittsburgh, 1960.

Data source for GNP implicit price deflator 1972-1973, 1958-1973, is: Statistical Abstract of the United States: 1974, p. 405, Table 695.

c. Computations for billions of gallons of treated cooling water 1973 are:

Billions of gallons of treated cooling water 1968	x	Factor to account for increase in treated water withdrawals 1968-1973	=	Billions of gallons of treated cooling water 1973
8,765.2	x	1.276	=	11,184

Data source for billions of gallons of treated cooling water 1968 is: Water Use in Manufacturing, p. 7-69, Table 4.

Data source for the factor to account for increase in treated water withdrawals 1968-1973 is: Statistical Abstract of the United States: 1974, p. 175, Table 295.

d. Data source for the cost of chlorination treatment per thousand gallons 1973 is: "Water Quality Conditions in Illinois."

e. Calculations for additional blow-down water costs are:

$$\left(\begin{array}{l} \text{Range of} \\ \text{salinity from} \\ \text{man-made} \\ \text{sources} \end{array} \right) \times \left(\begin{array}{l} \text{California's} \\ \text{additional blow-down} \\ \text{water costs 1970} \\ \text{(in \$ millions)} \end{array} \right) \times \left(\begin{array}{l} \text{GNP} \\ \text{implicit private} \\ \text{price deflator} \\ \text{1970-1973} \end{array} \right) \div \left(\begin{array}{l} \text{California's boiler and} \\ \text{cooling water used} \\ \text{(in billions of gallons)} \\ \text{Seven western regions} \\ \text{boiler and cooling water} \\ \text{used (in billions of gallons)} \end{array} \right) = \text{Additional} \\ \text{blow-down} \\ \text{water costs} \\ \text{(in \$ millions)}$$

$$(.30, .40) \times .73 \times 1.13 \div \left(\frac{211}{1184} \right) = 1.4-1.8$$

Data on range of salinity from man-made sources were derived from the following: Tihansky, Dennis P., Economic Damages to Household Items from Water Supply Use, U. S. Environmental Protection Agency, EPA-600/5-73-001, July 1973.

U.S. Department of Interior, Westwide Study Report on the Critical Water Problems Facing the Eleven Western States, 1974.

Data source for California's additional blow-down water costs is:

Sonnen, Michael B., "Quality Related Costs of Regional Water Users," paper presented at the January 29-February 2, 1973, ASCE National Meeting on Water Resources Engineering, Washington, D.C., p. 26 (Santa Ana Watershed was assumed to represent California).

Data source for boiler and cooling water use is: Water Use in Manufacturing, pp. 7-69, Table 4.

Data source for GNP implicit price deflator 1970-1973 is: Statistical Abstract of the United States: 1974, p. 405, Table 658.

Computations and Data Sources for Damages to Agricultural Water Uses:

$$\begin{array}{l} \text{1948 Cost of sediment} \\ \text{removal from drainage} \\ \text{ditches and irrigation} \times \\ \text{canals (in \$ millions)} \end{array} \times \begin{array}{l} \text{GNP Implicit} \\ \text{price deflator} \\ \text{1948 - 1973} \end{array} = \begin{array}{l} \text{Agricultural water} \\ \text{use damages} \\ \text{(in \$ millions)} \end{array}$$

34

x

1.933

=

66^a

Data source for the 1948 cost of sediment removal from drainage ditches and irrigation canals is: American Society of Agricultural Engineers, Paper 70-701.

Data sources for GNP implicit price deflator 1948-1973 are as follows:
 Drieling, Richard, Bureau of Economic Analysis, Department of Commerce, personal communication, April 1975.
Statistical Abstract of the United States: 1974, p. 405, Table 658.

- a. Calculations for the range of damages to agricultural water uses are:

Agricultural water use damages (in \$ millions)	x	Arbitrary factor of plus and minus 25 percent	=	Range of agricultural use damages (in \$ millions)
66	x	.75, 1.25	=	50-83

Computations and Data Sources for Damages to Commercial Fisheries

Damages to commercial fisheries 1970 (in \$ millions)	x	Factor to account for price increases	=	Damages to commercial fisheries (in \$ millions)
73, 13, 100	x	1.40 ^b	=	102, 18, 140

- a. Data sources for damages to commercial fisheries are as follows:
 Tihansky, Dennis P., "An Economic Assessment of Marine Water Pollution Damages," Proceedings of the Third International Conference on Pollution Control in the Marine Industries, June 1973, p. 304, Table III.
 Weddig, Lee J., National Fish Institute, Inc., Washington, D. C., personal communication, January 1973.
 Bale, H. E., Jr., Report on the Economic Costs of Fishery Contaminants, National Marine Fisheries Service, U. S. Department of Commerce, Rockville, Md., October 1971.
 Council on Environmental Quality, Ocean Dumping: A National Policy, 1970.

Unger, Samuel G., et al., National Estimates of Water Quality Benefits, Development Planning and Research Associates, Inc., October 1974, p. 61.

Dodson, Harold, Water Quality Office, U. S. Environmental Protection Agency, personal communication March 1975.

- b. Data sources for the factor to account for price increases is: Statistical Abstract of the United States: 1974, p. 647, Table 1103.

Computations and Data Sources for Domestic Damages:

Per capita damages (in dollars)	x	GNP implicit price deflator 1970-1973	x	1973 population (in millions)	x	Factor to account for man-induced pollution	x	Domestic damages (in \$ millions)
8.63, 3.12, 17.06 ^a	x	1.138 ^b	x	210 ^b	x	.168 ^c	x	346, 125, 685

- a. Data source for per capita damages is: Tihansky, Dennis P., Economic Damages to Household Items from Water Supply Use, U. S. Environmental Protection Agency, EPA 600/5-73-001, July 1973 (hereafter Economic Damages to Household Items from Water Supply Use), p. 63.
- b. Source of GNP implicit price deflator 1970-1973 and 1973 population data is: Statistical Abstract of the United States: 1974, p. 405, Table 658, and p. 5, Table 2.
- c. Calculations for the factor to account for man-induced pollution are:

$$\left(\begin{array}{l} \text{Proportion of} \\ \text{total damages} \\ \text{attributed to} \\ \text{surface water} \end{array} \right) \times \left(\begin{array}{l} \text{Proportion of} \\ \text{man-induced} \\ \text{surface water} \\ \text{pollution} \end{array} \right) + \left(\begin{array}{l} \text{Proportion of} \\ \text{total damages} \\ \text{attributed to} \\ \text{ground water} \end{array} \right) \times \left(\begin{array}{l} \text{Man-induced} \\ \text{ground water} \\ \text{pollution} \\ \text{factor} \end{array} \right) = \text{Factor to} \\ \text{account for} \\ \text{man-induced} \\ \text{pollution}$$

$$(.339 \times .30) + (.661 \times .10) = .168$$

Data source is: Economic Damages to Household Items from Water Supply Use, p. 69.

Computations and Data Sources for Materials Damage

$$\begin{array}{rclcl}
 \text{Navigation} & & \text{Sedimentation} & & \text{Materials} \\
 \text{damages} & + & \text{damages} & = & \text{damage} \\
 \text{(in \$ millions)} & & \text{(in \$ millions)} & & \text{(in \$ millions)} \\
 \\
 167^a & + & 253^b & = & 420
 \end{array}$$

a. Calculations for navigation damages are:

$$\begin{array}{rclcl}
 \left(\begin{array}{l} \text{Corrosion to} \\ \text{steamboats and} \\ \text{barges 1958} \\ \text{(in \$ millions)} \end{array} \right) \times \left(\begin{array}{l} \text{GNP implicit} \\ \text{price deflator} \\ \text{1958-1973} \end{array} \right) & + & \left(\begin{array}{l} \text{Cost of} \\ \text{dredging} \\ \text{sediment 1948} \\ \text{(in \$ millions)} \end{array} \right) \times \left(\begin{array}{l} \text{GNP implicit} \\ \text{price deflator} \\ \text{1948-1973} \end{array} \right) & = & \text{Navigation} \\
 & & & & \text{damages} \\
 & & & & \text{(in \$ millions)} \\
 (4.6 \times 1.539) & + & (83 \times 1.933) & = & 167
 \end{array}$$

Data source for corrosion to steamboats and barges 1958 is: Bramer, Henry C., Economically Significant Physicochemical Parameters of Water Quality for Various Uses, Mellon Institute, Pittsburgh, Pa., 1972, p. 3.

Data sources for GNP implicit price deflators 1958-1973 and 1948-1973 are as follows: Statistical Abstract of the United States: 1974, p. 405, Table 658.

Dreiling, Richard, Bureau of Economic Analysis, U. S. Department of Commerce, personal communication, April 1975.

Data source for cost of dredging sediment is: American Society of Agricultural Engineers, Paper 70-701.

b. Calculation for sedimentation damages is:

$$\begin{array}{rclcl}
 \left(\begin{array}{l} \text{Cost of flood} \\ \text{plains deposition} \\ \text{1948} \\ \text{(in \$ millions)} \end{array} \right) + \left(\begin{array}{l} \text{Value of storage} \\ \text{space lost in} \\ \text{reservoirs 1948} \\ \text{(in \$ millions)} \end{array} \right) + \left(\begin{array}{l} \text{Value of cleaning} \\ \text{and added maintenance} \\ \text{1948} \\ \text{(in \$ millions)} \end{array} \right) \times \left(\begin{array}{l} \text{GNP implicit} \\ \text{price deflator} \\ \text{1948-1973} \end{array} \right) & = & \text{Sedimentation} \\
 & & & & \text{damages} \\
 (50 + 50 + 31) & \times & 1.933 & = & 253
 \end{array}$$

Data source for the cost of deposition on flood plains, value of storage space lost in reservoirs, value of cleaning and added maintenance is: American Society of Agricultural Engineers, Paper 70-701.

Data sources for GNP implicit price deflator 1948-1973 are as follows: Dreiling, Richard, Bureau of Economic Analysis, U. S. Department of Commerce, personal communication, April 1975. Statistical Abstract of the United States: 1974, p. 405, Table 658.

c. Calculation of materials damage is:

Materials damage	x	Arbitrary factor of plus and minus 25 percent	=	Range of sedimentation damages
420	x	.75, 1.25	=	315 - 525

4. Computations for Health Damages from Water Pollution

The estimates of damages to health resulting from water pollution were computed by use of three primary sources:

- Lackner (1973)
- Liu (1970)
- Sokoloski (1973).

Computations utilized Lackner's, Liu's, and Sokoloski's estimates of the number of cases of acute clinical illnesses, and an associated value of morbidity and/or mortality for each disease category. A compensation estimate was derived from employees compensation and the value of household work data.

Table III-6 below summarizes the potential health damages from water pollution. Data sources are as follows:

- a. Data source is: Liu, Oscar C., Illnesses Associated With Human Enteric Viruses, Northeast Water Supply Research Laboratory, U. S. Environmental Protection Agency, Narragansett, Rhode Island, 1970.
- b. Data source is: Lackner, Jack, Safe Drinking Water Act of 1973: Estimated Benefits and Costs, U. S. Environmental Protection Agency, 1973.
- c. Data source is: Sokoloski, A., Economic Benefits of an Adequate Supply of Safe Water, U. S. Environmental Protection Agency, 1973.

Table III-6. Estimates of Annual Health Damages from Drinking Water Quality

Disease	(Cases of morbidity,	Cases of mortality) x (Value per case:	= Total damages
	morbidity,	morbidity, mortality)	(in \$ millions)
Infectious hepatitis	60,000 ^a -130,000 ^b	1,000 ^a	1,250 ^b -2,250 ^a , 100,000 -250,000 175-543
Salmonellosis	16,000 ^c -58,000 ^b		1,250 ^b 20-73
Shigellosis	700 - 42,000		1,250 ^b 1-53
Acute gastroenteritis and diarrhea	1,000,000 ^b -2,000,000 ^{a*}		30 ^a -50 ^b 30-100
Amebiasis	10,000 ^b		1,250 ^b 13
Typhoid fever	1,500 ^b		1,250 ^b 2
Acute abdominal disease	10,000 ^a		200 ^a 2
Spontaneous abortion	10,000 ^a		300 ^a 3
Aseptic meningitis	5,000 ^a		300 ^a 2
Congenital heart anomalies	5,000 ^a -12,000 ^c	500 ^a	2,000 ^a 100,000 ^a -250,000 60-149
Myocarditis and pericarditis	1,000 ^a	100 ^a	1,000 ^a 100,000 ^a -250,000 11-26
Encephalitis	50 ^a		2,000 ^a **
Herpangina	2,000 ^a		200 ^a **
Platyrodynia	2,000 ^a		200 ^a **
Giardiasis	150 ^c		1,250 **
			320-967
			644

* Workdays lost equal upper bound, rather than number of illnesses.

** Value less than \$1 million.

REFERENCES

- American Society of Agricultural Engineers, professional paper 70-701.
- Bale, H. E., Jr., Report on the Economic Costs of Fishery Contaminants, U.S. Department of Commerce, National Marine Fisheries Service, October 1971.
- Barker, Bruce and Paul Kramer, "Water Quality Conditions in Illinois," in Statewide Water Resource Development Plan 1972, Illinois Department of Transportation, Division of Water Resource Management, 1973.
- Bramer, Henry C., The Economic Aspects of the Water Pollution Abatement Program in the Ohio River Valley, Ph.D. Dissertation, University of Pittsburgh, 1960.
- Bramer, Henry C., "Economically Significant Physicochemical Parameters of Water Quality for Various Uses," Mellon Institute, 1972.
- Burt, Oscar R., and Durward Brewer, "Estimation of Net Social Benefits from Outdoor Recreation," Econometrica, September 1971.
- Council on Environmental Quality, Environmental Quality - 1972, The Third Annual Report of the Council on Environmental Quality, August 1972.
- Council on Environmental Quality, Ocean Dumping: A National Policy, 1970.
- Ditton, Robert and Thomas Goodale, Marine Recreation Uses of Green Bay: A Study of Human Behavior and Attitude Patterns, Technical Report No. 17, University of Wisconsin, Sea Grant Program, December 1972.
- Dodson, Harold, U.S. Environmental Protection Agency, Water Quality Office, personal communication, March 1975.
- Dreiling, Richard, U.S. Department of Commerce, Bureau of Economic Analysis, personal communication, March 1975.
- Ericson, Raymond K., Valuation of Water Quality in Outdoor Recreation, forthcoming Ph.D. Dissertation, Colorado State University, 1975.
- Lackner, Jack, Safe Drinking Water Act of 1973: Estimated Benefits and Costs, U.S. Environmental Protection Agency, 1973.
- Liu, Oscar C., Illnesses Associated With Human Enteric Viruses, U.S. Environmental Protection Agency, Northeast Water Supply Research Laboratory, 1970.
- Meyer, Philip A., Recreational and Preservation Values Associated With the Salmon of the Fraser River, Fisheries and Marine Service, Vancouver, B.C., Canada, Information Report Series, No. PAC/N-74-1, 1974.
- Owens, Gerald P., Outdoor Recreation: Participation, Characteristics of Users, Distances Traveled, and Expenditures, Ohio Agricultural Research and Development Center, Research Bulletin 1033, April 1970.

Sokoloski, A., Economic Benefits of an Adequate Supply of Safe Water, U. S. Environmental Protection Agency, 1973.

Sonnen, Michael B., "Quality Related Costs of Regional Water Users," paper presented at the ASCE National Meeting on Water Resources Engineering, 29 January - 2 February 1973.

Tihansky, Dennis P., "An Economic Assessment of Marine Water Pollution Damages," Proceedings of the Third International Conference on Pollution Control in the Marine Industries, 5-7 June 1973.

Tihansky, Dennis P., Economic Damages to Household Items from Water Supply Use, U. S. Environmental Protection Agency, July 1973.

Unger, Samuel G., et al., National Estimates of Water Quality Benefits, Development Planning & Research Associates, Inc., November 1974.

U. S. Bureau of the Census, Census of Manufacturers, 7th Subject Report Water Use in Manufacturing, U. S. Government Printing Office, 1970.

U. S. Bureau of the Census, Governmental Finances in 1972-73, Series GS73, No. 5, U. S. Government Printing Office, 1974.

U. S. Bureau of the Census, Statistical Abstract of the United States: 1974, 95th ed., Washington, D. C. 1974.

U. S. Bureau of Outdoor Recreation, The 1970 Survey of Outdoor Recreation Activities - Preliminary Report, U. S. Department of Interior, February 1972.

U. S. Bureau of Outdoor Recreation, Outdoor Recreation - A Legacy for America, U. S. Department of Interior, December 1973.

U. S. Department of Commerce, Survey of Current Business, July 1974.

U. S. Department of Interior, Westwide Study Report on the Critical Water Problems Facing the Eleven Western States, 1974.

U. S. Federal Highway Administration, Cost of Operating an Automobile, U. S. Department of Transportation, April 1974.

U. S. Fish and Wildlife Service, National Survey of Fishing and Hunting 1970, U. S. Department of Interior, 1972.

Walker, Kathryn E. and William H. Gauger, The Dollar Value of Household Work, New York State College of Human Ecology, Information Bulletin 60, 1973.

Weddig, Lee J., National Fish Institute, Inc., Washington, D. C., personal communication, January 1973.

TECHNICAL REPORT DATA <i>(Please read Instructions on the reverse before completing)</i>		
1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE National Damages of Air and Water Pollution		5. REPORT DATE
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) H. T. Heintz, Jr.; A. Hershaft; G. C. Horak		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Enviro Control, Inc. 11300 Rockville Pike Rockville, Maryland 20852		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. Contract No. 68-01-2821
12. SPONSORING AGENCY NAME AND ADDRESS Office of Research and Development U.S. Environmental Protection Agency Washington, D. C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA-ORD
15. SUPPLEMENTARY NOTES		
16. ABSTRACT <p>This report presents updated estimates of the national damages in 1973 of air and water pollution. Information on pollution damages heretofore scattered among numerous sources has been compiled and updated to reflect "best estimates" of the economic significance of the impacts of air and water pollution. The conceptual foundations of damage estimates are discussed. The source studies for each damage category are surveyed, and updated best estimates including a range to represent their uncertainty, are then developed. Best estimates of air pollution damage are developed for the following categories: human health, \$5.7 billion; aesthetics, \$9.7 billion; vegetation, \$2.9 billion; and materials, \$1.9 billion. The total best estimate for air pollution damages is \$20.2 billion with a range of \$9.5 to \$35.4 billion. A methodology for estimating human populations at risk to air pollutant levels is described. Best estimates of water pollution damages are developed for the following categories: outdoor recreation, \$6.5 billion; aesthetics and ecological impacts, \$1.5 billion; health damages \$0.6 billion; and production losses, \$1.7 billion. The total best estimate for water pollution damages is \$10.1 billion with a range of \$4.5 and \$18.7 billion. The caveats qualifying these damage estimates are discussed. Even so, the study recognizes that tradeoffs are inherent in any decision making process and a better understanding of those tradeoffs will allow for improved decision making.</p>		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field Group
Economic Surveys Economic Analysis Air Pollution Water Pollution	Environmental Economics Environmental impacts Benefit/Cost Analysis Economic Efficiency Pollution Abatement Benefits Pollution Effects	5C 20A
18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECRETARY CLASS (<i>This Report</i>) UNCLASSIFIED	21. NO. OF PAGES -
	20. SECURITY CLASS (<i>This page</i>) UNCLASSIFIED	22. PRICE

INSTRUCTIONS

1. **REPORT NUMBER**
Insert the EPA report number as it appears on the cover of the publication.
2. **LEAVE BLANK**
3. **RECIPIENTS ACCESSION NUMBER**
Reserved for use by each report recipient.
4. **TITLE AND SUBTITLE**
Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.
5. **REPORT DATE**
Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected (*e.g., date of issue, date of approval, date of preparation, etc.*).
6. **PERFORMING ORGANIZATION CODE**
Leave blank.
7. **AUTHOR(S)**
Give name(s) in conventional order (*John R. Doe, J. Robert Doe. etc.*). List author's affiliation if it differs from the performing organization.
8. **PERFORMING ORGANIZATION REPORT NUMBER**
Insert if performing organization wishes to assign this number.
9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
Give name, street, city state, and ZIP code. List no more than two levels of an organizational hierarchy.
10. **PROGRAM ELEMENT NUMBER**
Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.
11. **CONTRACT/GRANT NUMBER**
Insert contract or grant number under which report was prepared.
12. **SPONSORING AGENCY NAME AND ADDRESS**
Include ZIP code.
13. **TYPE OF REPORT AND PERIOD COVERED**
Indicate interim final, etc., and if applicable, dates covered.
14. **SPONSORING AGENCY CODE**
Leave blank.
15. **SUPPLEMENTARY NOTES**
Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.
16. **ABSTRACT**
Include a brief (*200 words or less*) factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.
17. **KEY WORDS AND DOCUMENT ANALYSIS**
 - (a) **DESCRIPTORS** - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.
 - (b) **IDENTIFIERS AND OPEN-ENDED TERMS** - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.
 - (c) **COSATI FIELD GROUP** - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field, Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).
18. **DISTRIBUTION STATEMENT**
Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.
19. & 20. **SECURITY CLASSIFICATION**
DO NOT submit classified reports to the National Technical Information service.
21. **NUMBER OF PAGES**
Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.
22. **PRICE**
Insert the price set by the National Technical Information Service or the Government Printing Office, if known.